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INTRODUCTION.

May 19, 20 and 21, 1938, marked the culmination of three years of preparation for the Dedication of the Benjamin Franklin Memorial when the Institute's new structure on the Benjamin Franklin Parkway in Philadelphia became a nation's shrine to the memory of the great man for whom it was named.

Of the numerous important gatherings and significant events which have taken place under its auspices in the one hundred and fourteen virile years since the foundation of The Franklin Institute, this Dedication marks another step forward and will always remain as an outstanding occasion in its history.

Attended by men and women of front rank in scientific circles, honored by distinguished delegates from societies, universities, colleges and associations in many countries, encouraged by outstanding organizations at home and abroad, and with the cooperation of Government, Military, Naval, Industrial, Professional and Youth interests, the occasion combined all the elements requisite to making the Dedication Ceremonies an occasion, the dominating spirit of which is expressed by the simple words

"In Honor of Benjamin Franklin."

The new home for Dr. Benjamin Franklin was the culmination of many years' effort. The start was made by money given to the Institute by the Board of City Trusts of Philadelphia, representing a bequest made by Benjamin Franklin

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

and entrusted to that municipal body, and an equal sum raised by the Institute. The next step was a movement from the Poor Richard Club of Philadelphia to give to our country a fitting memorial to that great American. Cooperation between the Poor Richard Club and The Franklin Institute resulted in an organization known as the Benjamin Franklin Memorial, Inc. This group, with the aid of eleven thousand public-spirited citizens, formulated the ideals for building around a heroic statue a home of usefulness where young and old could receive useful help and inspiration through the truths of science. In the new structure the age old activities of The Franklin Institute, its Library, Research, Lectures, Medal Awards, would be reinforced by a dynamic science museum. This was done. Four years ago the new building opened its doors, but its dedication had to wait completion of the statue of Franklin. At last it was finished and the great citizen and scientist ready for a suitable housewarming.

The celebration was planned to take three days; the first for Franklin—Patriot and Man, the second for the Philosopher and Educator, and the third to the Printer and Business man.

DEDICATION CEREMONIES.

FIRST DAY.

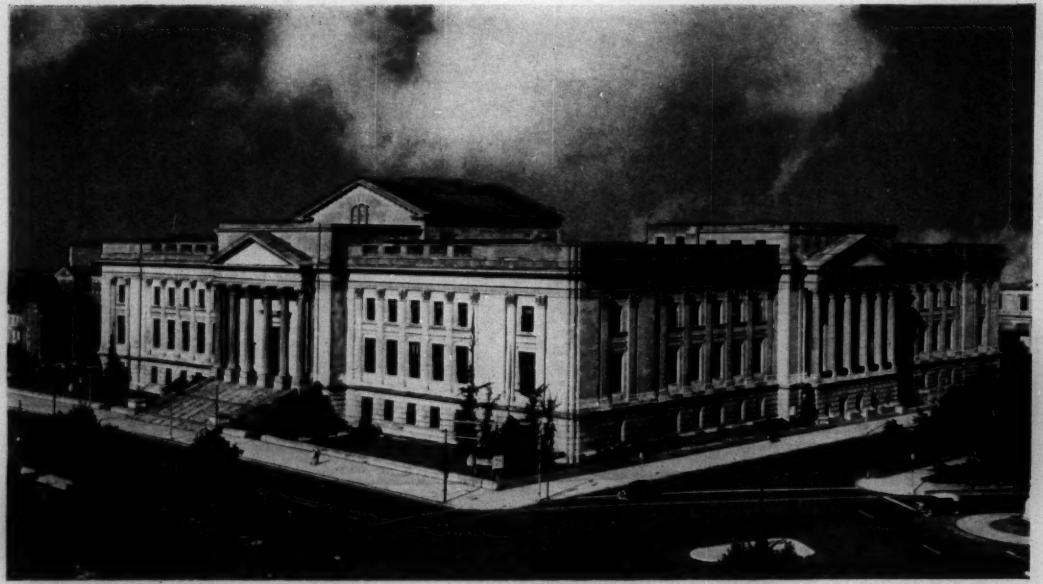
Delegates: The institutions of learning and industry which assisted in the celebration by appointing delegates and sending greetings were received in Franklin Hall in the morning. These included fifty-seven from foreign lands.

Besides the greetings given to the Institute, the Royal Society of Great Britain presented a facsimile of the page out of its Minute Book which recorded Benjamin Franklin's admission to that society.

The Royal Institution of Great Britain presented a colored etching of a hundred years ago showing its library. Five states presented their flags for the new Memorial.

During the morning also the Benjamin Franklin Branch Post Office was officially opened in the building by the sale of the new half cent stamp bearing the new statue head of Franklin. The first sale was made by the Postmaster of Philadelphia to the President of the Institute.

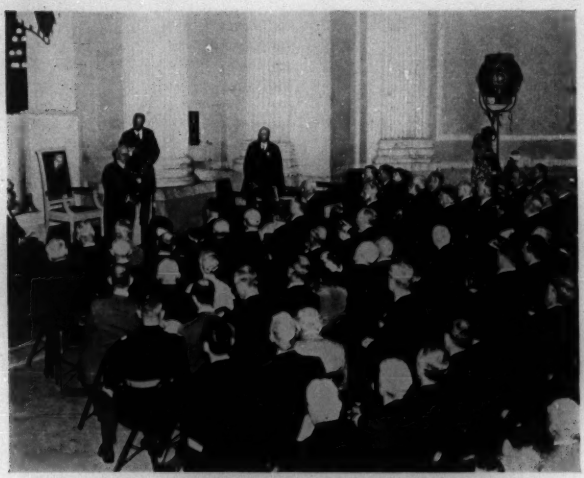
The "first day" sales of the Franklin stamp amounted to 1,483,756 stamps alone and 224,901 cached first day covers.



The Benjamin Franklin Memorial.

Simultaneously the stamp exhibit was opened to the public. In this sixty exhibitors, including the President of the United States and the Secretary of the Interior, displayed stamps, many for the first time and said to have been the finest limited exhibition ever held in America.

In the same Hall the United States Bureau of Printing and Engraving actually printed the new six cent bicolored air mail stamp.



Greeting the Delegates, Franklin Hall.

Unveiling: The thousands of invited guests were seated on the east side of Twentieth Street facing the main steps at the top of which was the unveiling party. On the steps were seated the combined school choruses of approximately 4,000 voices, together with united school bands of 150 pieces and the Valley Forge Military Academy Band.

Escorted by the First Troop, Philadelphia City Cavalry, the French Ambassador to the United States, the Secretary of Commerce, who represented the President of the United

States, together with City and Institute officials, came down the Benjamin Franklin Parkway. The ambassadorial salute of 19 guns was fired and upon arrival at the Institute and after being greeted, the French national anthem was played.

After invocation by the Rt. Rev. Francis M. Taitt, Bishop of the Protestant Episcopal Diocese of Pennsylvania, the Hon. George Wharton Pepper was introduced by President Staples and spoke as follows:

Benjamin Franklin Branch, U. S. Post Office.
Sale of first sheet of Franklin stamps by the Postmaster to the President of the Institute.

"This is moving day for Benjamin Franklin. You in the audience are looking at his new home and I am addressing you from his front steps.

"Years ago, before 1790, Dr. Franklin lived in a modest Philadelphia house in what was then called Franklin's Court. He occupied that house till the day of his funeral. All of him that was mortal was buried in the churchyard of Old Christ Church; but for one hundred and forty years we

Philadelphians failed to provide for his immortal spirit any place which he could call his own.

"It is true that there were several places in town where he was always welcome. There was the home of the American Philosophical Society at Fifth and Chestnut Streets, the outgrowth of the Junto which he himself had founded. There was the office of the Philadelphia Contributionship on South Fourth Street, the fine old fire insurance company of which

Arrival of Distinguished Guests.

he was a founder. There was the Library Company of Philadelphia, now on Locust Street below Broad, which, too, was his creation. There was the Pennsylvania Hospital at Eighth and Spruce Streets, another of his pet projects. There was the University of Pennsylvania which traces its origin to his fertile brain. The Franklin Institute, founded in 1824 and housed for a hundred years on Seventh Street south of Market, was for him a sort of laboratory and workshop. In all these places he could drop in whenever he

pleased and in all of them he was always heartily greated and worthily entertained. But still he had no house which he could call his own—no place where he could welcome visitors, discuss with them the latest developments in his many fields of activity and exhibit to their eager eyes the actual workings of the ingenious and useful mechanisms in which he takes such great delight.

"This continued to be the situation until 1929. In that year something happened. The Poor Richard Club, a group of worthy citizens who had chosen him as patron, decided to make a supreme effort to build an adequate house for him. The idea was suggested to Cyrus H. K. Curtis. That great citizen gave it hearty approval. Under his inspiring leadership an organization was formed to transform the idea into reality. In spite of a world-wide depression, millions of dollars were quickly subscribed by interested citizens, and in an amazingly short time the great house was built. Today we are assembled to make a formal tender of it to him and to invite our great friend to move in and occupy it permanently.

"Because it is easier for us to realize his presence if we can actually see him, it was decided that a worthy statue of him should be made and placed in the great central hall. The generosity of the late William McLean made this possible and the genius of James Earle Fraser, the sculptor, has actually created it. In a few minutes this statue will be unveiled by one of his living lineal descendants in the presence of others of them. When this has happened, Dr. Franklin will have moved into his new house and thenceforth we shall always know where to find him.

"The dedication of a memorial is apt to be a funereal proceeding but the dedication of this Franklin Memorial is an altogether joyful occasion. The reason is that we mean to keep Franklin among us as a living being so that we may get to know him well. If we do this he will influence our lives and help us to become better citizens.

"The process of getting to know a man is quite simple. It has three phases. We make ourselves familiar with his countenance and bearing; we listen to what he has to say to us; and we watch him as he goes about his daily work and note the sort of things in which he is interested.

"In Franklin's case the genius of the sculptor makes it possible for us to actually look him in the eye. We are about to issue, in popular attractive form, some booklets which will familiarize us with his very words and in them we shall be able to find his message to us. In the building, which today we dedicate, we shall find him whenever we choose to call; because in all the manifold exhibits contained in this great building Franklin himself will seem to be the moving force which gives life and vitality to all its wonders.

"On behalf, therefore, of the goodly company of citizens who have made this memorial possible, I now dedicate this great building to our fellow-citizen, Benjamin Franklin. I accounce officially that from this time forward the BENJAMIN FRANKLIN MEMORIAL will be his permanent home, and I extend a hearty invitation to all people everywhere to visit him and make him their friend."

Count Rene Doynel de Saint Quentin, French Ambassador, then said:

"Few foreigners have held such a preponderant place in the history of France as Benjamin Franklin. None has obtained, by a more unanimous consent of the whole nation, the moral French citizenship. Hence, an official tribute from France is paid to his memory today.

"Benjamin Franklin mastered the French language but very late in life. Nevertheless, while still a young man, his penetrative mind had delved into the common fund of all civilizations. As early as 1733, Poor Richard disclosed ideas dear to French historians or philosophers of the same period, and that with a smiling simplicity which enabled him to go through the narrow boundaries of the elite and reach the largest body of opinion.

"However, he was not revealed to France before about 1750 and only then as a scientist. Because he did not know the scientific theories of the time, and perhaps, for that very reason, did not encumber himself with obsolete formulas, but went straight to reality, he had, if not discovered, at least explained and made intelligible to all a natural force which was to change completely modern life—I refer to electricity. He was immediately acknowledged a master by the French

scientists, and King Louis XV officially tendered congratulations to him.

"War between England and France having been declared shortly afterwards, Benjamin Franklin, as a loyal Englishman and good citizen of Pennsylvania, took an active part in the struggle of that State against the French forces threatening on land and sea. But at that time knowledge knew no boundries. Following the victory of Anglo-American armies,

Address of Rene Doynel de Saint Quentin, Ambassador of France.

Franklin went for the first time to Paris in 1767 and was greeted with honors by scientists and also by economists, convinced like himself of the vital importance of agriculture for national prosperity.

"The events that followed are too well known to be recalled at length. The name of Benjamin Franklin is associated with all the memorable dates of the American Revolution. He was, with Jefferson, one of the authors of the Declaration of the Independence of 1776 and one may well believe that he

took no small part in drafting this document, wherein the feelings of the American nation were expressed in a manner which was to conquer all the free spirits in Europe.

"In consequence, he was rightly appointed as a member of the delegation sent by the Congress of Philadelphia to Paris. He found in France lively sympathies for the American cause. The French nation, already living in the expectation of momentous events, had welcomed the American Revolution as the dawn of a new era. Benjamin Franklin appeared as its worthy emissary. His sincerity won the esteem of all; his moderation and his smile reassured those that the word 'Revolution' could easily frighten. The dignity of his attire appealed to one of the most brilliant societies which nevertheless felt the ardent desire to renew itself by leading a simpler life. If it be true, as reported by his biographers, that he threw his wig overboard when on the ship carrying him to France, he could not have followed better inspiration.

"Benjamin Franklin was a master of diplomacy for he succeeded always to win the full confidence of his listeners by his thorough loyalty. He knew the art of discussing without contradicting and hence without antagonizing. He accepted slowness and hesitancy without impatience. He never tired of explaining America to the French, and France to the Americans.

"Franklin deserved the main credit for the treaty of alliance signed at Versailles in 1778 between the United States and France. He directed its application in close understanding with the French Foreign Minister Vergennes. During the long four years that war lasted he never appeared depressed by bad news nor dazzled by good news. He would smilingly says: 'All will be right,' infusing into everyone the confidence he felt. Meanwhile, he secured from France an ever-growing assistance until the victory was finally achieved.

"However, he was not a man inclined to prolong war uselessly. In this instance, as in many others, he was ahead of his time. He believed in the necessity of a friendly agreement between France, England and the United States, for all three nations in the course of their history had heard the call of liberty. Moderate towards his opponent, mindful of the

interests of his ally, he contributed in no small measure to the peace which was finally signed on June 20, 1783.

"He remained another two and one-half years in Paris, where he had been appointed in 1778 diplomatic envoy of the American Government. He lived through glorious years amid universal esteem and affection. Not merely from France, but also from every country of the world, princes and their representatives, scholars, writers, women, came to see him.

"Thus was he really the Ambassador of the United States to Europe and of the New World to the Old. When he left France, in the King's carriage, he was eighty years old. But during the five remaining years of his life which he spent in Philadelphia, he kept in close touch with public life, and in 1788, the eloquent speech he delivered to the Convention was the deciding factor leading to the unanimous vote of the Constitution.

"Upon his death, on April 17, 1790, the National Assembly, which since a few months ruled the destinies of the young French Revolution, decided a three-day national mourning.

"Benjamin Franklin remains in the memory of all Frenchmen, the true type of the great scientist guided by a strong desire to help his fellowmen, and it is not without reason that French science is represented today by the eminent Professor Martin, Director of the Pasteur Institute, which as you know was founded by another great benefactor of mankind. Franklin also embodies in our minds the cooperation of all the energies of a country for the defense of liberty. By one of those chances of history which so often ring very true, it is in the street of Paris named after Franklin that lived and died the great Frenchman who, in the hour of mortal danger, led his country to victory by national union and with the help of the United States. That man was Georges Clémenceau.

"And so Franklin appears to us through the centuries as a trustee of the friendship between France and America.

"It is a great honor for me today, as I stand before the fine Institute which bears his name in the town of Philadelphia which he so dearly loved and so nobly served, to bring to his

memory the grateful tribute of the Government of the French Republic."

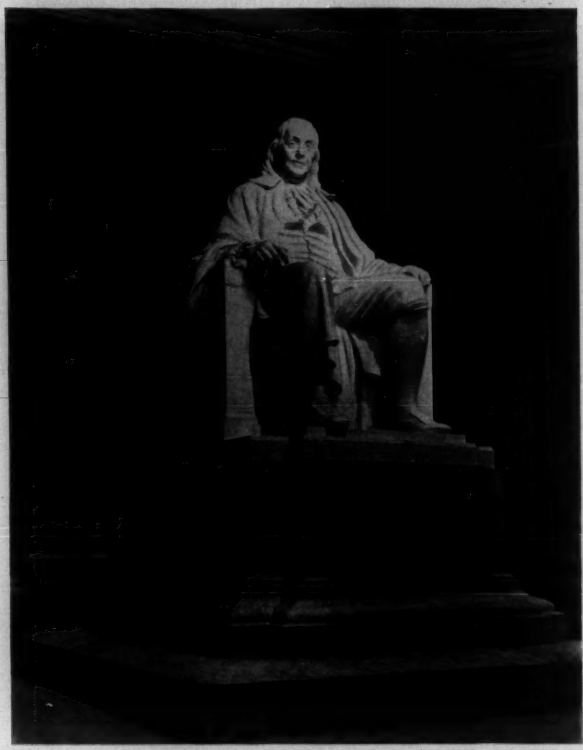
The unveiling party then walked into Franklin Hall while the combined bands and choruses gave one of the two prize songs, "America, My Wondrous Land." The Hon. Daniel C. Roper, Secretary of Commerce, read the following message from the President of the United States:

The Unveiling.

"One of the greatest and most useful of public men in our colonial and early national periods, Franklin with every generation looms ever large in world history. Now, nearly a hundred and fifty years after his death, his accomplishments assume their due proportions. It is in keeping with his strongly practical nature that the Memorial you are dedicating today will serve a useful purpose."

Then by means of a modern electrical development, the photoelectric cell, twelve-year-old Louisa Johnston Castle,

granddaughter of Franklin Bache, Esq., direct descendant of Franklin, by flashing a beam of light from an electric torch, unveiled the heroic marble statue of her fifth great-grand-



Benjamin Franklin.

father. Twelve other children, all direct descendants, watched the ceremony.

A bugle call by Boy Scout trumpeters told the throngs outside that the statue was unveiled and then to the accom-

paniment of the second prize song, "Oh, Wisest of Men," the small unveiling group went back to the platform at the top of the main entrance. This was followed by the "Star, Spangled Banner," sung by the entire audience.

Immediately following the exercises, the audience filed up

Vice-president Wetherill, Chairman of Program Committee, Greeting the Sculptor, James Earle Fraser.

the steps between lines of Marines and Blue Jackets and into Franklin Hall.

A reception and tea was held in the Graphic Arts Section for distinguished guests. At this time Count Rene de Saint Quentin presented to the Institute, from the Republic of France, through President Staples, two Franklin Medals

which had been struck from the original dies made by the French Government in the year 1787. At the same time, honoring The Franklin Institute for its service to science and its two executives for their successful administration of this great event in scientific circles, as well as for other efforts to bring the scientists of America and France together, in the name of his country The Ambassador bestowed the decoration of the Chevalier of the Legion of Honor on Mr. Philip C.

Dinner of the Poor Richard Club. Honorable Daniel C. Roper, Secretary of Commerce, Addressing the Guests.

Staples and Dr. Henry Butler Allen, President and Secretary-Director, respectively, of The Franklin Institute.

Military and Naval Display: During the first day around the Institute modern mechanized material was demonstrated by the Army to show the application of electricity to national defense. There were included aircraft and anti-aircraft demonstrations.

So that our visitors and the citizens could see at first hand progress in naval preparedness, the Navy Department had

docked the U.S.S. *Arkansas* and the U.S.S. *Warrington* at the Municipal Pier for the three day-period. The League Island Navy Yard held "open house" on the second day.

Poor Richard Club Dinner: In the evening in Franklin Hall around the newly unveiled statue, the Poor Richard Club held a dinner under the toastmastership of its president, Charles H. Grakelow. Here the Hon. Daniel C. Roper eulogized the simple, clear-minded greatness of Franklin.

SECOND DAY.

Morning and Afternoon: At the Institute the second day was given over to lectures by outstanding speakers on Franklin and the several fields of science in which he was interested as a "philosopher." In order to accommodate all who came, the sessions were held in the Planetarium chamber.

The lectures given in both morning and afternoon sessions are printed in the order given:

"Benjamin Franklin in Saint Andrews, 1759," SIR JAMES C. IRVINE, Principal and Vice Chancellor, University of Saint Andrews, Saint Andrews, Scotland.

"Photography and the Advance of Pure Science," DR. C. E. K. MEES, Director, Research Laboratory, Eastman Kodak Company, Rochester, New York.

"Acids and Bases," DR. GILBERT N. LEWIS, Dean, College of Chemistry, University of California, Berkeley, California.

"Electricity as a Fluid," DR. GEORGE D. BIRKHOFF, Mathematician, Harvard University, Cambridge, Massachusetts.

"Influence of Astronomy on Science," DR. FOREST RAY MOULTON, Permanent Secretary, American Association Advancement of Science, Washington, D.C.

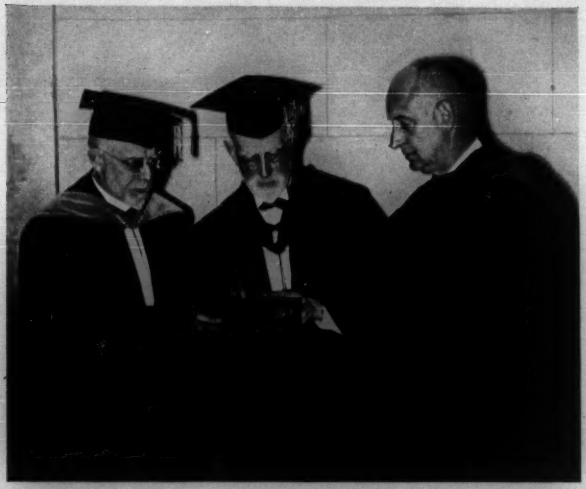
"Volcanoes, Geysers and Hot Springs," DR. ARTHUR L. DAY, former Director of the Geophysical Laboratory, Carnegie Institution, Washington, D.C.

"L'Hospitalisation des Maladies Contagieuses," DR. LOUIS MARTIN, Director, The Pasteur Institute, Paris, France.

"Human Heredity and Modern Genetics," DR. THOMAS H. MORGAN, Zoologist, California Institute of Technology, Pasadena, California.

"Must All Rare Plants Suffer the Fate of Franklinia," DR. MERRITT L. FERNALD, Botanist, Harvard University, Cambridge, Massachusetts.

In the evening of the second day the University of Pennsylvania, collaborating with The Franklin Institute, awarded honorary degrees to several of the distinguished scientists who participated in the Dedicatory exercises. At the same



Presentation of Medals.

time The Franklin Institute awarded its medals for scientific achievements.

The Academic Procession was formed in the Library of the Institute and was made colorful by the caps and gowns of the scientists from abroad representing foreign universities. There were approximately 160 in the procession.

The exercises were held in Franklin Hall at the base of the statue and were attended by delegates, members of the Institute and friends of the gentlemen who were honored.

Dr. Thomas S. Gates presided in the name of the University for the conferring of degrees, and Mr. Philip C. Staples, as

The Academic Procession.

President of The Franklin Institute for the award of medals. Those who received degrees of Doctor of Science were as follows:

GEORGE DAVID BIRKHOFF, Mathematician, Harvard University, Cambridge, Mass. Winner, American Mathe-

matical Society prize 1923. A.A.A.S. prize 1926—Pontifical Academy of Sciences prize 1933.

ARTHUR LOUIS DAY, Physicist—Former Director, Geophysical Laboratory, Carnegie Institution, Washington, D.C.

GILBERT NEWTON LEWIS, Chemist, Dean of the College of Chemistry, University of California, Berkeley.

THOMAS HUNT MORGAN, Zoologist, California Institute of Technology, Pasadena, Calif. Nobel Prize winner 1933.

LOUIS MARTIN, Bacteriologist, Director, Pasteur Institute, Paris, France.

The Institute awarded its medals to the following:

Longstreth Medal to

CLARENCE W. BALKE, Ph.D., Fansteel Metallurgical Corporation, Chicago, Illinois.

FREDERICK HELLWEG, Captain, U.S.N., Ret. and

PAUL SOLLENBERGER, United States Naval Observatory, Washington, D.C.

FREDERICK C. LANGENBERG, Sc.D. (awarded posthumously), and

NORMAN F. S. RUSSELL, President, United States Pipe and Foundry Company, Burlington, New Jersey.

CARL ZEISS, Incorporated, Jena, Germany, and

DYCKERHOFF AND WIDMANN AKTIEN GESELLSCHAFT, Berlin, Germany.

Clark Medal to

ROBERT BRINTON HARPER, The Peoples Gas Light and Coke Company, Chicago, Illinois.

Henderson Medal to

CLYDE C. FARMER, Westinghouse Air Brake Company, Pittsburgh, Pennsylvania.

Levy Medal to

STEWART S. KURTZ, JR., Sun Oil Company, Marcus Hook, Pennsylvania, and

ALGER L. WARD, United Gas Improvement Company, Philadelphia, Pennsylvania.

Potts Medal to

LARS O. GRONDAHL, Ph.D., Union Switch and Signal Company, Swissvale, Pennsylvania.

Cresson Medal to

EDWIN H. LAND, The Land-Wheelwright Laboratories, Incorporated, Boston, Massachusetts.

Franklin Medal to

WILLIAM FREDERICK DURAND, Ph.D., LL.D., Stanford University, California.

CHARLES AUGUST KRAUS, Ph.D., Brown University, Providence, Rhode Island.

THIRD DAY.

The third day was devoted to FRANKLIN: PRINTER AND BUSINESS MAN. In keeping with this theme the morning was devoted to lectures on Applied Science which were attended by industrialists as well as delegates and other visiting friends of the Institute.

The program was as follows:

"IT'S CALLED ELECTRICITY"—Dr. Willis R. Whitney, Vice President in charge of Research, General Electric Company, Schenectady, New York.

"THE TREND OF CIVIL ENGINEERING SINCE FRANKLIN"—Dr. Abel Wolman, Professor of Sanitary Engineering, Johns Hopkins University, Baltimore, Maryland.

"ENGINEERING AND HEALTH"—Dr. Harvey N. Davis, President, Stevens Institute of Technology, Hoboken, New Jersey.

The afternoon of the third day was devoted to the young people. Approximately ten thousand children came together under the leadership of George W. Elliott, Executive Secretary, Philadelphia Chamber of Commerce, in what was designated as the "Young Philadelphia Parade." Forming at Broad and Spring Garden Streets, the column, consisting of forty uniformed units, junior and senior high school students, five drum and bugle corps and bands, Girard College cadets in khaki uniform, Veterans of Foreign Wars, and one

thousand Boy Scouts, marched south on Broad Street to City Hall Square, thence northwest along the Benjamin Franklin Parkway to Twentieth Street and east to the plaza in front of the Franklin Memorial. This group was preceded by a platoon of mounted police followed by the Police and Firemen's Band of Philadelphia and three companies of patrolmen.

When the line of march came to rest, colors were massed in a group of more than five hundred flags and banners.

Young Philadelphia Parade.

The special feature of the afternoon for the young people was the award of prizes to twenty-five children who had distinguished themselves in a prize competition sponsored by the Poor Richard Club in the form of an essay contest on "What Franklin Did for America and for Us Who Live Today."

After appropriate remarks by President Staples of The Franklin Institute, and Mr. Charles H. Grakelow, President of the Poor Richard Club, Sir James C. Irvine, Principal and

Vice Chancellor, University of St. Andrews, Scotland, presented the prizes to the various winners of the contest.

The presence of the large number of children who had marched in the parade, the massed colors, the brilliant tints of the uniforms of the various units, the stirring music of the bands, all blended to present a magnificant spectacle.

After the awards had been presented, the thousands of children thronged Franklin Hall, to catch a first glimpse of the

Young Philadelphia Parade. Sir James C. Irvine Addressing the Children.

statue of Franklin, the great American. All in silence they marched past and paid their youthful tribute to the man who has meant so much to his country.

On Saturday evening, May 21st, the concluding ceremony of the three-day Dedication functions consisted of a dinner in the ballroom of the Bellevue-Stratford Hotel, which afforded a brilliant conclusion to the successive events preceding it. This function was attended by seven hundred and fifty guests.

The dinner was preceded by a reception in honor of the Honorable Herbert C. Hoover, former President of the United States, who, with the Honorable Roland S. Morris, President of the American Philosophical Society and formerly Ambassador of the United States to Japan, were the guest speakers.

The dinner was attended by a distinguished group representing many interests and activities of the City of Philadelphia, as well as by the delegates, lecturers and other distinguished guests of the Institute during the Dedication Ceremonies.

Speakers at the Dedication Banquet.

Presiding as toastmaster, Mr. Philip C. Staples introduced the Honorable Roland S. Morris as the first speaker. Mr. Morris presented a most interesting address touching upon the many diverse interests of Benjamin Franklin.

Mr. Staples then introduced the Honorable Herbert C. Hoover, who, in an extremely interesting speech, punctuated by wit and humor, spoke on the theme of "Benjamin Franklin and Citizenship."

An impressive interlude took place at the dinner, preceding the speeches, when an "Ode to the Flags of the Revolution" was presented by the Color Guard of the Pennsylvania Society

of Sons of the Revolution. A poem, written in blank verse, descriptive of the famous flags of that period of our country's history, was presented by Mr. Frank Earle Schermerhorn, of the Color Guard. After a procession of the flags across the stage, they were presented in mass formation. As each flag was described, it was presented briefly apart from the others, for the veneration of the diners. The entire ceremony, simple and short, was singularly effective.

Immediately following this presentation, Colonel Clarence P. Franklin, Commander of the Color Guard, on behalf of the Pennsylvania Society, Sons of the Revolution, presented to The Franklin Institute, through its President, Mr. Philip C. Staples, a replica of the "Benjamin Franklin Flag."* Tradition tells us that when Franklin was our ambassador at Paris, it was brought very forcibly to his attention that his struggling country should have an emblem to fly, especially on ships at sea. The need was acute and Franklin, the resourceful, met it by having made a flag which, before there was time for naval action to take place, was replaced by the Stars and Stripes.

Throughout the three days' celebration special exhibitions were held in the Museum of The Franklin Institute. Through the cooperation of other educational institutions and industries, many unusual exhibits were on display showing science and technology of Franklin's day and its advance since that time.

* See frontispiece.

DEDICATION OF THE BENJAMIN FRANKLIN MEMORIAL LECTURES.

BENJAMIN FRANKLIN IN ST. ANDREWS.*

BY

SIR JAMES C. IRVINE,

Principal and Vice Chancellor, University of Saint Andrews, Saint Andrews, Scotland.

Benjamin Franklin was not the first American to expound in the New World the scientific philosophy which began with Bacon. He had his predecessors, but in any age and under any circumstances he would stand out as a remarkable figure and as a distinctive type. To few men can the posthumous verdict of history have been more kind, whether we regard him as a social reformer, a political philosopher or an experimental scientist.

When we now pay homage to the memory of the scientific father of his country, it is natural that our minds should dwell on the fields of human knowledge in which Franklin was specially interested and with which the Institute bearing his name is identified. But it is seemly that we should also seek to stretch across the gap which separates us from the middle of the XVIII century and find new human contacts with the man himself. For this reason I invite your attention to a romantic episode in Franklin's career which meant much to him then and means much to me today.

Franklin was not a vain man; the trappings of state and the emblems of nobility made no appeal to him, yet he must have known that although among his contemporaries were numbered many men endowed with unusual powers and abilities he himself was fitted to take a place in the foremost rank as at least their intellectual equal. Honours and dignities which came to him were modestly accepted as his due and of these there was one of which he was inordinately fond—the right to describe himself as "Doctor Franklin." It was my own University of St. Andrews in distant Scotland which first gave him that right and it is part of her proud inheritance to claim Franklin as an adopted son.

* Presented Friday morning, May 20, 1938.

The essential facts are known only in barest outline, and accordingly I have made it my task to complete the story so far as the documentary evidence permits, remembering always that a mere chemist must walk with care when he ventures to trespass on the domain of the historian. The search has not been easy for although the records of the University of St. Andrews are complete from 1428 onwards, the entries relating to the bestowal of honorary degrees are brief until after the beginning of the XIX century. But the original letter despatched to Franklin announcing his election as a Doctor of Laws is in existence as is also his degree diploma signed by each member of the Senatus Academicus. Morever, it is known that Franklin made a special journey to St. Andrews to receive his degree in person, but unlike Dr. Johnson who made the same pilgrimage a few years later he had no Boswell in his train to take notes for our benefit today. In short, there are many gaps in the story and much left unexplained. For my own part, it has always been something of a mystery that Franklin's experimental work, no matter how great its distinction, should have been signalled out and recognised in this way by the little band of Professors who, 180 years ago, were holding together "the oldest, the smallest and the most romantic of the Scottish Universities" through a time of poverty and stress.

Let us transport ourselves back to the year 1759 and endeavor to reconstruct the circumstances which led to the despatch of this welcome invitation to the American philosopher-statesman. Franklin was then in his 54th year and behind him there lay a record of stern endeavor and high achievement. In this assembly there is no need to recount the earlier stages of a career which progressed—with the inevitability which seems to surround the footsteps of genius—from the printer's office in Philadelphia to a position of renown in the world of science and affairs; but we must recognize that Franklin, his early struggles over, found himself beset with difficulties. The circumstances of the times were calculated to disturb a mind so prophetic and to destroy idealism. The future of his country, its claims to self-government and the possibility of its development as part of a Commonwealth of Nations must have occupied his thoughts to an extent which

could have left but little room for reflection on the electrical researches with which he had occupied his leisure. He stood in the middle stage of his career. It was, I have no doubt, a perplexed and disappointed man who sailed for Europe to plead the cause of the people of Pennsylvania before the Privy Council and who remained in London as the agent-general of the colony. A measure of consolation came to him to leaven his anxieties for if he found the house of British politics divided against itself he was made welcome by the homes of learning. The French Academy admitted him as a Foreign Associate and, much to his gratification, he was elected a Fellow of The Royal Society of London. But the Universities of Britain, then seven in number, were slow to follow this lead, being still a little inclined to look askance at the new experimental science. Philosophy, theology, classics and mathematics reigned supreme and, such being the case, it is all the more remarkable that experiments carried out 3,000 miles away on a subject so mysterious as electricity should first have attracted the attention of the ancient Scottish University.

On the 12th day of February, 1759, the Senatus Academicus of St. Andrews was convened by one of my predecessors to dispose of a single item of business. The Minute of the proceedings is disappointingly brief and reads:

> "Conferr'd the Degree of Doctor in Laws on Mr. Benjamin Franklin famous for his writings on Electricity. And appoint his Diploma to be given him gratis. The Clerk & Archbeadles dues to be paid by ye Library Questor."

Compared with the elaboration of present day methods the procedure was refreshingly simple, but even at the time the regulations in force demanded that every promotion to a degree should be sponsored by a member of a College. The records show that there were then thirteen members of Senatus entitled to submit the names of distinguished men as the recipients of honorary degrees and that of these electors nine were present at the meeting on February 12th. To one of the nine must belong the honour of having recommended Franklin and an appendix to the Minute seems to identify Professor David Gregory as the man who in this way brought distinction to St. Andrews.

"Mr. Gregory signed the new separate Register which was attested in common form."

From the position of these words in relation to the main text of the Minute the evidence seems conclusive but some doubt exists as to the precise nature of "the new separate Register" to which Mr. Gregory so obligingly added his name. The University had lately passed through a period of reconstruction when two of the constituent colleges had been amalgamated and in the consequent transference of Professors (of whom Gregory was one) it was necessary for each to sign a special register as a preliminary to admission to the United College. It transpires, however, that Gregory had already executed this formal act and indeed it was in the capacity of a Professor in the United College that he attended the Senatus meeting. This leaves no reasonable doubt as to the nature of the paper he signed on 12th February and further enquiry has served to support the conclusion that it was the nomination of Franklin as a Doctor of Laws. It will be noted that the Senatus Minute makes no reference to any activity other than Franklin's work on electricity—it is for scientific learning that the degree is bestowed—and accordingly the life-story and scholarly interests of each member of Senatus present at the meeting have been explored. Latin, Greek, Hebrew, Divinity, Logic, Moral Philosophy, History, Mathematics and Natural Philosophy were all represented at the Round Table and Franklin's scientific work could have been known only to two members. Attention at once focuses on Gregory and Professor David Young, the latter an ageing man in frail health who occupied the Chair of "Natural and Experimental Philosophy." Despite his professorial attachment to what is now included under Physics Young took no part so far as can be traced, in the primitive electrical studies then pursued in Scotland, but on the other hand his younger colleague Gregory was closely identified by inheritance and interest with Physical science. The son of Professor Charles Gregory the mathematician, he was the nephew of that David Gregory who, as Professor of Astronomy at Oxford, was the friend of Newton. His scientific lineage goes even further back for he was the great-nephew of the famous James Gregory to whom we owe the Gregorian

telescope; he came of fine scientific stock and a more appropriate sponsor for Franklin could not well be imagined.

It will be observed that no condition was laid down by the University that Franklin had to appear personally to receive the degree. Indeed the form in which the letter sent to him is worded (not to mention the remission of fees) implies that the Senatus did not expect his attendance. The distinction was not merely offered but "conferr'd" and according to the custom of the times the use of the title "Doctor" became operative at once. That Franklin in his busy life should have made the tedious journey to Scotland in order to comply with academic formality is at once a testimony to his appreciation of the honour and his reverence for a custom hallowed by the usage of more than three centuries. Difficulties of transit in a country which had scarce emerged from the confusion of Prince Charlie's Rising might well have been counted as an excuse for taking the Doctorate in absentia, yet in the Autumn of the year we find Franklin on his way to St. Andrews by post-chaise in the company of his friends Professor John Anderson of Glasgow and the mysterious Dr. Baird of Philadelphia. The latter deserves more than a passing word partly for the reason that his identity has been difficult to trace and more particularly because he has been credited with being responsible for securing the academic honour for his friend Franklin. Dr. Baird first springs to notice in the pages of the Autobiography where Franklin refers to him as a native of St. Andrews who had shown him much kindness, and it is a natural assumption that Dr. Baird might have played a part in bringing Franklin's work to the notice of his old University. But enquiry has shown that his contact with Scotland is so slender as to place this almost out of consideration. A search of the Burgh and University archives has revealed that Baird received his early education not at St. Andrews but at Leyden and that he graduated M.D. in Rheims in 1733. Four years later he took his Doctorate in Medicine at St. Andrews where he practiced for only a short time and he had already landed in the New World before David Gregory, Franklin's subseuqent nominator, was born, Dr. Baird would doubtless be delighted at the thought of his Philadelphian friend being enrolled in his

own academic brotherhood but it is almost unlikely that he played any part whatsoever in bringing this to pass.

The little cavalcade approached St. Andrews by the road from Perth crossing the river Eden by the bridge where, as recorded in the accounts of the Lord High Treasurer of Scotland, another party, nearly 300 years earlier, had paid "To ane puir wif at the Brig of Dersee as the King raid by VIII d." This romantic spot passed, the distant view of St. Andrews which greeted Franklin's eyes must have affected him profoundly. Even, today, when the city has expanded and become in part modernized the sight arouses deep emotion and, through the medium of Oliphant's drawings which were in course of preparation at the time of Franklin's visit, we can reconstruct the scene exactly as he saw it. On its rocky promontory, stretching far out into the blue distance of the North Sea, stood the old ecclesiastical capital of Scotland—its outline fretted with towers which told of a past splendour. As the travellers drew nearer they would discover that Castle, Cathedral, Priory and Monastery were little more than picturesque ruins, but in the centre of these mournful reminders of religious strife the Tower of St. Salvator's College dominated the City and lent majesty to it, for of all these great foundations the University alone had survived the tempest of reform. The conditions are described by many contemporary writers including Defoe, John Loveday and Thomas Pennant, but the most human record is that of Samuel Johnson who included St. Andrews in his Journey to the Western Islands. After deploring the tumult and violence of Knox's reformation he pays tribute to the gallant struggle of the University and we may take his account (supplemented by that of the faithful Boswell) as a true picture of that stronghold of learning during the most difficult period of its long history.

There is no account of where Franklin and his two travelling companions resided during their visit but they were probably housed as guests of Professors for evidence exists in plenty that if academic purses were light the warmth of Scottish hospitality had not suffered in consequence. The story again becomes definite on the day of graduation—the 2nd of October, 1759—when the ceremony took place in the old Parliament Hall of the University. This building with but little change is still in use, an unpretentious structure carrying

on the frontage to South Street the Armorial Bearings of the Chancellors. Internally, it consisted of a long low ceilinged panelled room with windows looking out on the peace and quiet of St. Mary's College Quadrangle. It is a beautiful room yet full of tragic memories. Originally the Library it had acquired its name through the fact that the Scottish Estates met there at times when Edinburgh offered less security. On the last of such occasions the sessions were devoted to the trial for high treason of the Officer Prisoners taken at the battle of Philiphaugh where the army of Marquis de Montrose suffered its first and final defeat. Six former St. Andrews students heard their death sentence in a room where they had spent quiet studious hours and it is surely not carrying conjecture too far to conclude that in the same room disquieting reflections must have stirred in Franklin's mind. The object of his visit to Europe cannot have been far removed from his thoughts and he must have been acutely aware of the political issues, then rushing to a climax, which were destined ere long to lead his country to struggle for independence by force of arms. Nevertheless for that brief hour we must think of him as essentially a happy man when, surrounded by friends, he received the academic tribute of Scotland.

In imagination we can look on at the ceremony, taking our place on the tier of raised benches flanking the wall: the windows overlook the College Garden where the thorn-tree planted by Mary, Queen of Scots, was even then 200 years old. The center of the floor is empty, the surrounding seats are occupied by senior members of the University while in the background stands a group of scarlet-gowned students. All eyes are turned on the central figure. Clad in the undress gown of a Doctor of Laws (out of the fashion of the University of Paris) Franklin kneels on the graduation stool in front of the President of Senatus who admits him in the customary form:

"Te ad gradum DOCTORIS LEGUM promoveo, aujus rei in symbolum super te hoc birretum impono."

At the words "hoc birretum" the graduate's head is covered for a moment with the historic "graduation cap." Today little more than a fragile square of black velvet, this cap belonged traditionally to John Knox and its adoption as the symbol of admission to the fellowship of the University began at the Reformation. It is, of course, the fashion of iconoclasts

to discredit a story so picturesque but this much is certain. In the University accounts there is a charge for repairing the cap dated nearly a century in advance of Franklin's time; and it is indisputably the same cap which is still in use and is taken out of its safe in the strong room on every graduation day. Whatever its origin, it has rested for a moment on many a distinguished head and only a man utterly devoid of imagination could escape a feeling of exaltation and consecration at its touch.

The hood of scarlet silk lined with white satin having been draped over the shoulders of the kneeling graduate he rises—no longer Mr. Benjamin Franklin but "Doctor Franklin"—the simple ceremony, conducted in terms of regulations made in 1428, is over. There is no complete record of those who were present as spectators but an early pen drawing of a graduation shows that students attended on such occasions and the University being in session on 2nd October, 1759, it may be taken as certain that many would avail themselves of the opportunity to see the distinguished visitor. The undergraduates of the period represented every phase of Scottish life—the names of noblemen and of ploughmen's sons are on the roll of 1759—but one stands out dramatically from all the others. It is JAMES WILSON, a name destined to be honoured throughout this country and especially in this City of Philadelphia. In October, 1759, Wilson, a youth of 17, was beginning his third year of study in the United College; his home was near St. Andrews and nothing is more likely than that he was present with his companions to see the famous American visitor. It is a romantic thought. The distinguished statesman and the young country lad were as far removed as two men could be for there is a wide gulf between LL.D.'s from Philadelphia and students of the third year from Fife. Yet within a few years fate brought them together in Pennsylvania where they worked side by side, each playing his part in laying the foundations of the United States of America. Today, most fittingly, they lie side by side not far from this spot; it was a long and arduous road they traversed from the Parliament Hall at St. Andrews to Christ Church in Philadelphia.

There is little more to tell. Franklin was in no haste to leave St. Andrews where he made new friendships and

consolidated a love for Scotland which he never lost. He was interested in student life and although it is unlikely that he encountered young James Wilson who lived at home with his parents and not in College he visited the students' rooms in St. Salvator's. There he prescribed for the young Lord Cardross, who lay dangerously ill, and did so with such success that more than twenty years later his former patient credited Franklin with having saved his life. Before leaving the City the Doctor presented an inscribed copy of his book "New Experiments and Observations on Electricity" (1754) to the University Library and at intervals within the succeeding fourteen years he donated other books, one being the first volume of the Transactions of the American Philosophical Society.

It is to me a pleasent thought that to the end of his life Franklin held Scotland in warm affection. "On the whole I must say," he wrote to Lord Kames, "I think the time we spent there was six weeks of the densest happiness I have ever met with in any part of my life, and the agreeable and instructive society we found there in such plenty has left an impression on my memory that, did not strong connections draw me elsewhere, I believe Scotland would be the country I should choose to spend the remainder of my days in." His heart warmed to the stirring tales of Scotland's struggle for liberty and responded to the wistful quality of her folk songs so that years later he and Sally played and sang them together. It is satisfactory to know, as a testimony to the merit of their performance, that the society of Philadelphia was charmed, although somewhat extravagantly, they "conceived the Scottish tunes to be the finest in the World."

I close on this note of Franklin's love for the country of which St. Andrews is the academic mother for in so doing we may reconstruct his thoughts when memory called him to look back on his graduation day. I feel sure the recollection brought happiness to him. He would be glad to conjure up a vision of the romantic city, to tread again her cobbled streets and to hear once more the benison of the ancient University. In the long history of St. Andrews no man carried the distinction of her doctorate more nobly than did Benjamin Franklin or obeyed the behest of the Homeric motto "to strive ever towards excellence."

PHOTOGRAPHY AND THE ADVANCE OF PURE SCIENCE.*

BY

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Photography started not as a science but as an art. It was invented by the artists in order that they might facilitate their own work; that they might add to their skill the mechanical skill in drawing of the lens. The early development of photography was too late for Franklin, but it was the type of work in which he delighted—absorbing, producing results of beauty, a hobby and yet a science. From that little group of men that gathered around Josiah Wedgwood at the end of the Eighteenth Century, the Lunar Club, came the work of Tom Wedgwood and then that of Fox Talbot, who invented the calotype process, the predecessor of our modern photographic system. How much at home Franklin would have found himself with Tom Wedgwood's experiments or with Fox Talbot at Lacock Abbey, making his first records on paper a hundred years ago. It is fitting that the Franklin Institute, which is a memorial to a printer, should have dealt so much in the last fifty years with the achievements of photography, for printing and photography are but two aspects of the graphic arts, and they are distinctly complementary to each other.

From its early days as an art, photography became a craft, developing as a steadily improving craft, giving results of ever greater beauty and quality, overcoming difficulties, and removing limitations. Always it was clear that the origin of this new art was in science; and always it was clear that its services to science would repay the services which science could render to it.

The science of photography is founded on the two great sister sciences,—chemistry and physics—and it was only as our knowledge of these grew that progress could be made on the problems of photographic science. Until recently, photo-

* Presented Friday morning, May 20, 1938.

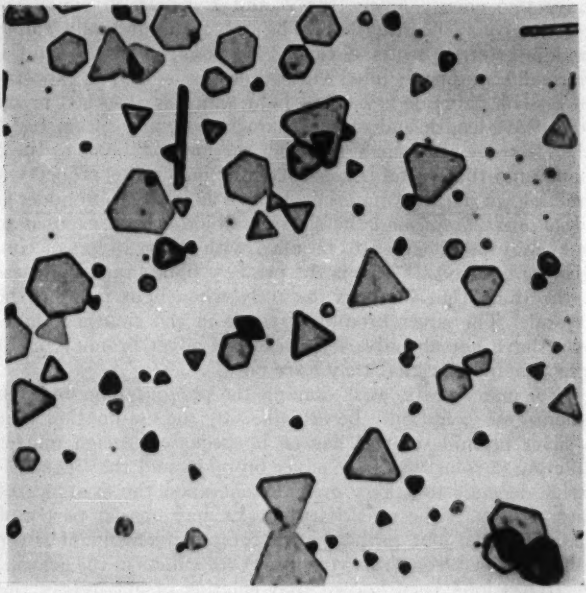
graphic science tended to consist of a chaos of observations, some of them of real value and others of very doubtful value, with little theory to connect them properly. It is only within the last few years that fact after fact has been falling into place in an ordered network. At the present time we can say that, while much remains to be done, we have a very clear and definite science of photography—something which can be written out and generalized upon and to which the missing parts can be added as more work is done.

Strictly speaking, many light-sensitive substances could be used for making photographic images, and the science of photography should be co-extensive with photochemistry itself; that is, with the chemistry and physics of light-sensitive substances. But, in practice, this is not the case, and the art of photography is almost entirely confined to the use of silver salts, so that the science of photography is necessarily pre-occupied with the very complex system of silver halide crystals dispersed in gelatin. Information as to the reactions which go on in the usually simpler systems used in photochemical investigations throws little light on the photographic process.

If we enlarge a photographic film under a microscope to about the limit of resolution of the microscope; that is, to some 2500 diameters, we shall find that it consists of a very complex system. On the base, which is usually cellulose nitrate or acetate, there are generally coated two different layers of gelatin containing silver halide crystals. These silver halide crystals are composed of silver bromide containing a small amount of silver iodide, and they are dyed to sensitize them to the longer wave-lengths of light. The crystals vary considerably in size but are of the same general shape (Fig. 1). They are triangles and hexagons, which are the natural forms of silver bromide, and they are held in photographic gelatin. Analysis would show that the film also contains a number of materials—glycerine, hardeners, and other things adapted to maintain the gelatin in good physical condition. When this film is exposed to light, the silver bromide crystals are affected in some way by an extraordinarily small amount of light, and they suffer some change. That change must take place in two steps and not quite instantaneously,

although it occurs in a very short fraction of a second. This is shown by the fact that the amount of change produced depends somewhat on the rate at which the light is supplied. If the light is supplied rapidly, and then the same amount of light is spread over a very long time, somewhat less effect is

FIG. 1.



Photomicrograph of silver bromide grains in an emulsion (2500×).

produced when the light is applied slowly—as if, for instance, a faucet were filling a bucket and the bucket had a small hole in it. But the analogy is not good because when the exposure is over, the change that has occurred is permanent; the image will keep for long periods. When Andrée's photographs found at the Pole thirty years after his balloon fell on the ice were

developed, the latent image was still in existence, having been preserved by the cold in spite of the immersion in sea water.

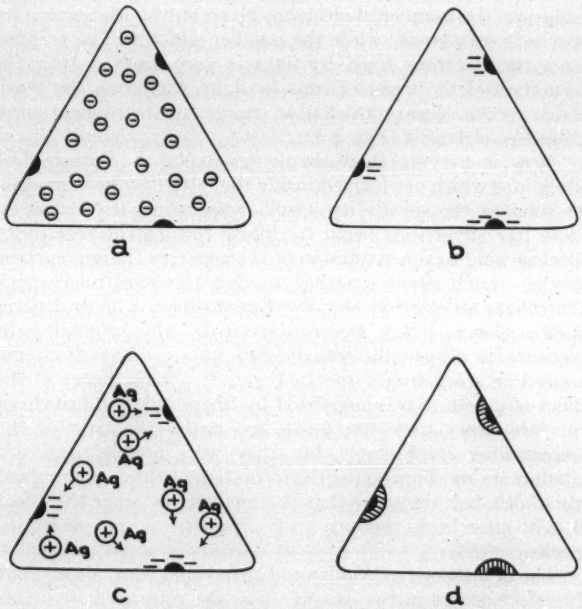
Recently, a consistent theory of the effect of light upon the silver bromide grains has come out of the work of our laboratories and from Professors Gurney and Mott of Bristol, England. In the first place, if we consider the energy diagram of a silver bromide crystal, we shall find that we have two energy levels, the *S* and *P* levels, in which the electrons may be situated. The *S* band is normally empty and is referred to as a *conduction band*. The *P* band is normally completely filled with the electrons. Upon exposure of a silver bromide crystal to light which is absorbed in the long wave-length end of the characteristic absorption band, the electrons are transferred from the lower *P* band to the *S* band, and the crystal becomes conducting. This property is well known in other materials, as well as in silver bromide, as *photo-conductance*, and the silver bromide crystal exposed to light may be imagined to be filled with a sort of gas of conducting electrons. This is the primary photographic process —the thing that happens instantly when light falls on the crystal. The silver bromide crystals in the emulsion, however, have not an unbroken surface of silver bromide or, at least, we imagine that they have not.

For many years, work done in the photographic research laboratories could only be explained by the assumption that a silver bromide crystal has on it specks of foreign matter differing in some way from silver bromide, and that its sensitivity depends to a very great extent upon the existence of these specks. The sensitivity specks may consist partly of metallic silver but probably are composed chiefly of silver sulfide derived from traces of sulfur compounds in the gelatin.

It has long been known that gelatins of apparently the same chemical properties behave differently when used for making photographic emulsions, and in an arduous research this was traced by S. E. Sheppard to the presence in the gelatin of traces of free sulfur compounds, which are presumably derived from the plants which the calves and their mothers ate. When gelatin is made from little animals, like rabbits, which avoid the hot-tasting plants, such as mustard containing sulfur, the gelatin does not contain these sulfur

compounds, so that it was not improper to state that "if cows didn't like mustard we wouldn't have any movies!" The sulfur compounds in the gelatin react with the silver bromide and produce specks of silver sulfide. Today, the emulsion maker deliberately selects the proper gelatin, and frequently

FIG. 2.



Silver bromide crystal, showing the formation of the latent image.

he adds auxiliary substances to produce the requisite sensitivity specks on its silver halide grain.

After exposure, we have a crystal on which are some of the sensitivity specks charged with free electrons (Fig. 2-*a*). The electrons will move about with great speed inside the crystal and very frequently reach the boundaries of the crystal, but

when they reach a sensitivity speck, they will be trapped by it for reasons connected with the energy levels, into which I need not go at the present moment; and the sensitivity speck will become negatively charged by the electrons that it has absorbed. Naturally, the sensitivity specks themselves will give off a few electrons if they are at normal temperatures, just as does any other solid body. During an ordinary exposure, the number of electrons given out by the sensitivity specks is very small; while the number which will be trapped from the electrons freed by light is very great. After the formation of the free electrons by light, therefore, the sensitivity specks acquire a negative charge by the absorption of these free electrons (Fig. 2-*b*).

Now, in a crystal there are always available, of course, free silver ions which are formed inside the lattice by heat motion. As soon as the sensitivity specks acquire negative charges, these free silver ions begin to diffuse toward the sensitivity specks owing to the attraction of the negative charge on these specks. Each silver ion that reaches the sensitivity speck neutralizes an electron already there to form a neutral silver atom. Hence, every electron freed by the original light exposure is eventually transformed into a silver atom deposited on a sensitivity speck (Fig. 2-*d*). This theory of the effect of exposure was suggested by Sheppard and Trivelli of our laboratory over ten years ago under the title of the *concentration speck theory*, but they were unable to give a satisfactory mechanism for the formation of the concentration speck although they saw that in some way or other the effect of light must be to produce a silver deposit at the sensitivity specks.

The new theory of Webb and Gurney and Mott shows that the effect occurs in two stages: first, the release of free electrons, which occurs instantaneously; and then the transformation of the free electrons by neutralization through the silver ions into silver atoms at the sensitivity specks. This accounts for what we may refer to as *the leaky bucket effect.* If the light is applied too slowly, free electrons are formed and go to the sensitivity specks, but meanwhile the sensitivity specks continually lose electrons by heat motion and, consequently, there are not as many silver atoms deposited at the

sensitivity specks as there should be. A certain minimum concentration of electrons must be built up in the crystal before the electrons begin to be trapped by the sensitivity specks. This explanation is shown to fit the facts because, when the loss of electrons from the sensitivity specks is reduced by greatly lowering the temperature, the rate at which light is supplied no longer affects the resulting image.

The action of light, then, on the silver halide crystals is, first, to produce instantaneously a charge of free electrons. Then these electrons are trapped at the sensitivity specks, and their charge is neutralized by silver ions, with the result that metallic silver is deposited around each sensitivity speck and forms the permanent nucleus which we call the *latent image*.

The great efficiency of the photographic process is due to the very small amount of work which is done by light in forming an image and the very large amount of work which is done by the chemical developer.

A photographic developer is a *reducing agent;* that is, it is a substance which is oxidized by silver bromide and, in being oxidized, reduces the silver bromide to metallic silver. The matter is, however, very complicated, and we are only beginning to understand the behavior of photographic development.

In the first place, not all reducing agents, by any means, are photographic developers. Photographic developers must develop exposed grains and not develop unexposed grains. If the reducing agents are too strong, they reduce the unexposed silver bromide and the whole of the film turns black, no image being formed. If the reducing agents are too weak, they won't reduce the silver bromide after exposure. For the substance to be a developer, it must have a certain power of reduction or, as we should say in electrochemical terms, a certain *reduction potential*. But there are substances which fall in the correct range of reduction potentials, as far as we can measure it, which still are not photographic developers. There are others which are photographic developers in the sense that they show an image on an exposed film but are not useful photographic developers because they do not develop satisfactory images in a reasonable time.

Great advances are being made in the chemistry of development. The physical chemistry of the oxidation and

reduction equilibrium is being worked out, and the reactions of the developing substances themselves are being followed; it seems likely that before long we shall be able to form a consistent picture of the whole phenomenon of development. It must be confessed, however, that at the present moment it is one of the least satisfactory parts of photographic science.

Silver bromide is sensitive to blue light and, of course, to all light of shorter wave-length, but the light of longest wave-length to which the material is sensitive is the blue. Consequently, photographic materials have always seen colors as of different relative brightnesses from those which they show to the eye. The visually bright reds, oranges, yellows, and greens are dark in a photograph, and the visually dark blues and violets are bright. Sixty years ago, it was discovered that this could be remedied by the addition of dye to the photographic emulsion, certain dyes sensitizing the silver bromide to the light which they absorbed and making the silver bromide grains sensitive to the absorption regions of the dye in the visible spectrum.

Progress in the application of this discovery was rather slow because very few dyes which would sensitize were known, and their application in practical photography had some serious disadvantages. During the last ten years, however, very great progress has been made both in the theory and in the practice of dye-sensitizing. On investigation, it was found that practically all polymethine dyes are sensitizers; that is, all those basic dyes in which the two nuclei are linked by CH groups; and once this was realized, it became possible to make vast numbers of dyes because many different nuclei can be used, the chain can be of different lengths, and various substituents can be inserted in the molecule. The peculiar technique of the organic chemist became available, and new sensitizing dyes "blossomed" on every hand! The verb is not inappropriate, for the dyes are very beautiful. They have bright colors and are beautiful crystals; many of them are pleochroic, so that they show iridescent effects.

By the use of these new dyes, it is possible to sensitize photographic emulsions to any part of the visible spectrum and far into the infra-red. The photographic spectrum in the infra-red, indeed, exceeds in wave-length range the visible

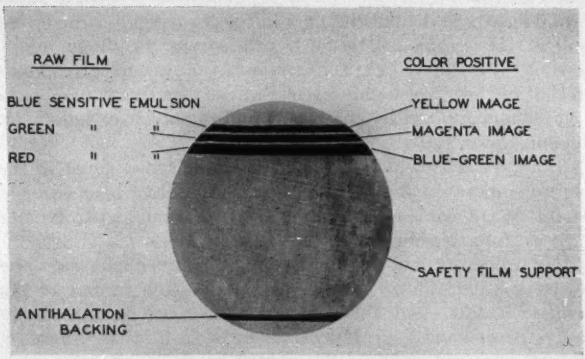
spectrum. Moreover, by using the dyes, we have achieved a considerable knowledge of the way in which they work. Studies of the relationship between dye concentration and sensitivity indicate that the optimum concentration for the sensitizing of a silver halide grain is a single layer of dye molecules attached to the whole surface of the grain, as if the flat plate of silver halide were covered with a little velvet pile of dye molecules, all of them firmly attached to the silver halide lattice, but free to resonate to the light which they absorb. When the dye molecule absorbs light, this resonation, perhaps, liberates the resonating electron whose existence is characteristic of the structure of the sensitizing dyes. The electron does not pass into the gelatin but into the silver bromide, where it takes its part in the formation of the latent image. It is replaced by an electron from the silver halide, so that the effective light sensitivity of the system corresponds to that of the silver halide itself; but the effective wave-length is no longer limited by the absorption of the silver halide—it depends upon the absorption of the dye.

The advances which have been made in sensitizing and the improvements in photographic emulsions have been applied to all sections of photography, but to none with greater success than to photography in natural colors.

All processes of color photography are dependent upon one simple system: Three pictures are made, each by one of the primary colors, and then these pictures are in some way projected or viewed so that they can be seen in the colors by which they were taken. The older processes of color photography involved the making of separate negatives through three color filters or the use on the film of microscopic colored filters, so that each unit of the film corresponded to one of the separation colors. The latest processes, however, are those in which the film is coated with three layers of light-sensitive emulsion, each of these being sensitive to one of the three primary colors (Fig. 3). Thus, on the film, next to the base, we may have a layer of red-sensitive emulsion, above it a layer of green-sensitive emulsion, and above that a layer of blue-sensitive emulsion. By exposure to light, the three images are formed simultaneously in the depth of the film, a total thickness no greater than that of the ordinary photo-

graphic emulsion film, or a few ten-thousandths of an inch. But, nevertheless, we really have three separate negatives,—one superimposed on the other—the bottom negative containing the red record; the middle, the green record; and the top negative, the blue record. These negatives by chemical processes are converted into color positives formed in dye, the bottom record, taken by red light, being transformed into a blue-green positive; the middle record, taken by green light, being transformed into a magenta positive; and the top record, taken by blue light, being transformed into a yellow

FIG. 3.



Cross-section photomicrograph of Kodachrome film.

positive. In this way, we obtain directly a color picture which, from the user's point of view, is no more difficult to make than ordinary black and white negatives. He simply uses a special film which is processed to the colors in a commercial laboratory specializing in such work. This process has already been applied on a large scale in amateur cinematography and is being used in certain other fields of photography. Its use is certain to extend, and we may, I think, look confidently to the day when a large portion of our photographic work will be done in color, and we shall get an

adequate representation of the wonderful world in which we live.

I have spoken at some length of the relation of photography to pure science, from which it was born. Let me turn for a moment to the other side of the story and mention a few of the ways in which photography pays its debt. The great value which photography has for the scientific worker is that it can be used for the integration of light. A short exposure produces a record. With a longer exposure, the record grows and continues to grow although the exposure be prolonged many hours. This is of the greatest value in astronomy, where the light of the stars can produce only a weak impression even in the great telescopes. It is by long continued exposures that we build up the images of the stars until we make statements with confidence about the most distant stars. To astronomy, in fact, photography is the invaluable tool. Other methods of observing can be used. In the early days, there was eye observation, and measurements can be made with photoelectric cells and other apparatus, but, fundamentally, the observing astronomer is a photographer, using his gigantic camera pointed towards the heavens and reserving for the future the interpretation of the photographs that he makes.

Photography has an application which is due to its ability to record instantaneous phenomena. If we smash a light bulb with a hammer, no eye can follow the fracture of the glass and tell us how it occurred. Since we can take photographs without difficulty at the rate of at least 10,000 a second, we can slow down the visual, instantaneous action and observe at leisure the phenomena in which we are interested.

Many of the rays which are of such importance in modern science are invisible to the eye. Only a small portion of the spectrum, indeed, is visible. The shortest waves of all, the *cosmic rays*, produce tracks upon photographic plates. The great region of the x-rays, with their value for medical diagnosis, has become accessible primarily by the use of photography. Recently, the longer x-rays, having very little penetrating power, have been used for the investigation of special matters such as the movements of insects or the structure of textiles. The whole ultra-violet region of the spectrum

can be handled only by means of photography, and especially photographic spectrophotometry is of the greatest importance in practice, while our ordinary analytical methods for use in metallurgy are dependent upon the ultra-violet spectrograph.

Photography is, in very truth, the most valuable tool of the physical sciences, without which many of our experimental methods would be impossible. In order to use that tool to the best advantage, it is necessary for scientific workers to understand its possibilities and its limitations. At the same time, it is both the duty and the interest of the photographic laboratories to increase those possibilities and to diminish those limitations. That can be accomplished only by the application of scientific knowledge to the problems of photography, which today, as in the past, are directly dependent for their solution upon the advance of pure science.

ACIDS AND BASES.*

BY

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In the last few years there has been a renewed interest in acids and bases and their nomenclature. Names are themselves of little consequence except in so far as they imply some systematic classification which may be of vital importance in the development of a science. Lavoisier, the greatest of all chemical systematists, used the word acid in a broad sense. Carbon dioxide was known as carbonic acid gas and sulfurous acid meant, as it still does in some languages, the anhydride SO_2. However, during the nineteenth century it became the fashion to regard hydrogen as an indispensable constituent of an acid, and finally the concept of acids and bases became so much restricted that in the minds of some of the early advocates of the ionic theory the only acid was an aqueous solution containing hydrogen ion, and the only base an aqueous solution containing hydroxide ion.

Such an idea could not be accepted by organic chemists, who recognized in ammonia and its derivatives substances which are bases in their own right, and not merely because they produce hydroxide ion when dissolved in water. So, also, the discovery of oxonium compounds led to further generalization and this process has continued up to the present.

It is possible, as I shall attempt to show in this paper, to discuss and define acids and bases merely from their behavior in chemical reactions without any theory of molecular structure. Nevertheless the development of the electronic views of valence made it easier to understand the essential characteristics of these two classes. In my book on "Valence," [1] after discussing various methods by which the idea of acids

* Presented Friday morning, May 20, 1938.

[1] "Valence and the Structure of Atoms and Molecules," Chemical Catalog Company, New York, 1923.

and bases could be extended, I proposed a very general definition of acids and bases. According to that definition, a basic molecule is one that has an electron-pair which may enter the valence shell of another atom to consummate the electron-pair bond; an acid molecule is one which is capable of receiving such an electron-pair into the shell of one of its atoms. Professor Sidgwick,[2] who has made such careful and extensive investigation of the consequences of our electronic conception of valence, calls the molecule which gives the electron-pair a *donor* molecule and the other an *acceptor* molecule. This expressive nomenclature I should be glad to adopt if I did not hope to show that his classification coincides absolutely with the classification of acids and bases, so that the need for new names disappears.

When the idea of the pairing of electrons was being first developed it was necessary to draw merely from the chemical behavior of substances some conclusions regarding electronic structure. Theoretical physics at that time offered no help except in so far as it had shown that the assumption of mere coulombic forces was incompatible with the existence of any stable atom or molecule composed of positive nuclei and electrons.

More recently, and largely since I last wrote on this subject fifteen years ago, conditions have radically changed. On the one hand, the development of numerous precise methods of measurement has furnished very exact information regarding the shape and size of many molecules.[3] On the other hand, quantum mechanics has revolutionized our idea of the interactions of material particles, especially in systems of small size. It is interesting therefore to find that the conclusions which were based on purely chemical, and largely qualitative, observations have retained their validity, and in many cases have been strengthened by the newer knowledge.

The principle of Pauli gave the first physical interpretation of the pairing of electrons, and Heitler and London were able to deduce from quantum mechanics the electron-pair bond.

[2] Sidgwick, "The Electronic Theory of Valency," Oxford University Press, 1929.

[3] See the interesting monograph by H. A. Stuart, "Molekülstruktur," J. Springer, Berlin, 1934.

It is true that the old idea of the exact localization of electrons in a molecule has had to be abandoned. Instead we have the more nebulous "electron cloud." However the denser part of this cloud, which represents the region in which the electron is by far the most likely to be, coincides, in the case of all compounds of the more nearly saturated type, with the electron positions demanded by chemical formulas. In unsaturated molecules where the "electron cloud" is less definitely localized, we often find that the properties cannot be well represented by a single chemical formula.

While it finally proved possible to reconcile quantum mechanics with the chemical requirement of the complete symmetry of the four bonds of methane, there is one chemical demand which the development of quantum mechanics has not as yet satisfied. It was an essential element in the original theory of the octet, not only that an atom bonded to four others would have the electron-pairs in tetrahedral positions, but that this would still be true even if one or two of the electron-pairs were not used in bonds. From this it was deduced that water would not have a linear structure nor ammonia a planar structure, and that the position of a non-bonding pair would be so situated at a corner of a tetrahedron as to produce optical isomerism, such as has been actually found in sulfonium compounds. Even to the simplest molecule the application of quantum mechanics is too difficult for anything more than approximate treatment. However, if an exact treatment ever becomes possible, we may be sure that it will show in the case of a molecule such as that of ammonia not only the concentration of "electron cloud" representing each of the bonds to the three hydrogen atoms, but also a fourth concentration in the form of a protuberance in the fourth tetrahedral position, and that this projection due to the unbonded electron-pair is the entity which is characteristic of basic molecules.

It is always of interest to find that some of our most modern scientific ideas have been vaguely anticipated by scientists of earlier centuries. One of the ideas of Lémery, a contemporary of Robert Boyle, is amusingly discussed in a well known history of chemistry, as follows:[4] "Yet one of his

[4] James Campbell Brown, "History of Chemistry," 1913.

theoretical conceptions was very odd, and shows how far astray a capable man may wander, when he deserts observed facts for philosophical speculations. He thought that chemical combination between two substances, such as an acid and a base, might be accounted for by supposing that the particles of the one substance were sharp, and those of the other porous, and that combination was effected by the *fitting of the points into the holes!*"

Before proceeding to defend my general definition of acids and bases, I may say a word concerning an even more general notion which has occasionally been suggested, namely, that an acid molecule is merely one in which there is some region which is electrically positive, that a basic molecule is one which in some part has an excess of negative electricity, and that the process of neutralization is the drawing together of the positive part of the one molecule and the negative part of the other through coulombic forces. Indeed, it has been found in many cases that it is possible to calculate, with good approximation, the heat of formation of a compound by this simple and old-fashioned expedient. This is due to the fact that Coulomb's law is nearly valid from large distances down to the immediate neighborhood of the molecule. However, in this neighborhood it is necessary to replace that law by the new principles of quantum mechanics, and it is in this neighborhood that occur most of the phenomena which are of particular interest to chemists. It is by no means possible by coulombic considerations to understand the limiting of carbon and its neighbors to a valence of four. When we consider the valence, or coördination number, of heavier elements, the coulombic view correctly predicts that the coördination number of a metallic ion will be larger the greater the positive charge on the ion, but it could in no way predict that these coördination numbers are almost always even; nor could it predict that in a coördination zone neutral molecules can be replaced by singly charged ions or by doubly charged ions without affecting the essential properties of the molecule.

Since the coulombic method often leads to approximately correct results, it is not surprising to find that, as H^+ is our type acid, so most anions have definite basic properties. Yet an ion like ClO_4^- is hardly a base at all, and while, in our

generalized system of acids, most positive ions are definitely acidic, such an ion as NR_4^+ cannot be regarded as an acid in any sense whatever. It is partly because the ions as acids and bases have been somewhat over-emphasized that we shall deal largely in this paper with acids and bases composed of neutral molecules.

The recognition by Brönsted and his school of such ions as the halide ions and acetate ion as true bases, together with the development of the concept of organic bases, tends to make the present recognized list of bases identical with my own. On the other hand, any similar valuable and instructive extension of the idea of acids has been prevented by what I am tempted to call the modern cult of the proton. To restrict the group of acids to those substances which contain hydrogen interferes as seriously with the systematic understanding of chemistry as would the restriction of the term oxidizing agent to substances containing oxygen. It is true that the term acid comprises at present not only hydrogen ion [5] but also undissociated acids, and correctly so, since H^+, owing to the phenomenon known as the formation of the hydrogen bond, is a dibasic acid. If, for example, it combines with the base OH^-, it can further combine with the base NH_3 to form the undissociated molecule NH_4OH. How does this behavior differ essentially from that of silver ion to which we ascribe the usual coördination number of two? Ag^+ can first combine with the base OH^-, and later with the second base NH_3, forming the molecule NH_3AgOH. Of course it might be supposed that hydrogen, because of its high mobility or its unique place in the periodic table, might give to hydrogen acids, or, as we may call them for short, H-acids, properties which distinguish them greatly from other acid substances, but as we proceed we shall find instead an astonishing similarity between H-acids and all the other members of the general acid group.

[5] I realize that it is unfashionable to speak of hydrogen ion. It was a familiar idea, even in the latter years of the nineteenth century, that hydrogen ion in water is largely hydrated. There must be several molecular species in solution such as H^+, H_3O^+, $H_5O_2^+$. If we wish to refer specifically to one of these, such as hydronium ion, H_3O^+, we may, but it seems best to keep the name hydrogen ion, and to use the symbol H^+ as shorthand designations for the whole group.

Before proceeding to a detailed consideration of the criteria of acids and bases, we may take provisionally as bases all those substances which, like hydroxide ion, "neutralize" hydrogen ion or any of the other members of our group of acids; and we may take as acids any of the substances which "neutralize" hydroxide ion or any of our other bases. We thus find that there is only a small number of elements whose atoms can contribute basic properties to a molecule. These are confined to the nitrogen, oxygen and fluorine families, occasionally carbon, and in one reported case a rare gas.[6] Choosing for our present purpose non-ionic bases which contain neither hydroxide nor labile hydrogen, we may take as examples of generalized bases *triethylamine*, *pyridine*, *acetone* and *ether*. These can be said to be arranged in the order of decreasing basic strength, but this is a question which we must later consider more carefully.

On the other hand, nearly all of the elements can act as acids; the only exceptions are the rare gases and probably the heavier members of the alkali and alkaline earth metals.[7] Choosing from the vast number of acids at our disposal, we will mention, for illustration, *sulfur trioxide*, *boron trichloride*, *stannic chloride*, *silver perchlorate*, *sulfur dioxide*, and *carbon dioxide*. These are arranged roughly in the order of diminishing acid strength. The acid properties of boron are due to

[6] Booth and Wilson (*J. Am. Chem. Soc.*, 57, 2273 (1937)) have obtained, from a study of freezing points, evidence of the existence of compounds between argon and boron trifluoride. They suggest that more stable compounds could be obtained with krypton and xenon. Since sulfur trioxide is a considerably stronger acid than boron trifluoride toward most bases, it may be found to give even more stable compounds with the rare gases.

[7] There can be no question that lithium ion and beryllium ion act as true acids and attach themselves, forming bonds of considerable strength, to basic electron-pairs situated on a typical anion such as Cl^-. As we proceed to the higher members of these two families, the strengths of such bonds become smaller until, in the case of cesium, it is doubtful whether in the gaseous state, or in solution in some solvent of low dielectric constant, the cesium ion is attached to a definite electron-pair on the anion. Instead we may consider cation and anion held together by purely coulombic forces and behaving essentially like two oppositely charged spheres. Such a molecule would frequently be said to possess a "polar bond," but personally I prefer to restrict the word "bond" to the cases in which two atoms are held together by an electron-pair, or, in the extremely rare type of the hydrogen molecule ion, by a single electron.

its tendency to complete its octet, or the stable group of four electron-pairs, those of tin and silver to the tendency to complete the stable groups of six and two electron-pairs, respectively. Whether we speak of valence or coördination number, we must recognize that in all cases the phenomenon is the same. The neutralization of an acid always consists in completing the stable number of electron-pairs which is characteristic of the atom to which the acid properties are due.

The stronger acids combine with the stronger bases to form stable compounds, while the weaker acids do not usually form compounds with the weaker bases. Such rough statements regarding the relative strengths of acids and bases are useful, but are nevertheless likely to be misleading. In studying the phenomenon of oxidation and reduction it is convenient to say that zinc is a stronger reducing agent than copper, but in the Daniel cell the direction of the current can be reversed when a little cyanide is introduced at the copper electrode. So in studying acids and bases we find that the relative strength depends not only upon the chosen solvent but also upon the particular base or acid used for reference. Thus in aqueous solution silver ion has little tendency to combine with hydroxide ion, and therefore with respect to this base we say that silver ion is a weak acid, but if a little ammonia is added to the solution, silver ion acts toward this new base as an acid comparable in strength with hydrogen ion of similar concentration. In general when metallic salts, or other compounds belonging to our set of acids, are dissolved in water, we often estimate their relative strengths as acids by the concentration of hydrogen ion which they set free, but we are only determining the strength of the acid towards the particular base OH^-, in the particular solvent water.

I may cite at this point several cases of specific action between certain acids and certain bases, all of which are observable in aqueous solutions, and which show how impossible it is to arrange our acids in any single monotonic order. Many heavy metallic ions, like silver ion, are relatively much stronger acids toward ammonia than toward water or OH^-. SO_2 is a weak acid and I^- and SCN^- are weak bases, but both these anions form fairly stable complexes

with SO_2 in aqueous solution, as can be noticed by the yellow color these complexes impart to the solution. The molecule $B(OH)_3$ can act as an acid (1) by giving off one or more hydrogen ions, (2) as a typical H-acid through the formation of the hydrogen bond, and (3) by giving boron its fourth bond, and thus completing its octet. This last type of acid behavior, which is shown very clearly by the ability of the ester $B(OR)_3$ to act as an acid,[8] is especially evident in the ability of boric acid to displace hydrogen from a simple alcohol to form the simple B-O-C linkage, and becomes extremely pronounced whenever the organic molecule has two basic atoms so situated that they can both combine with a single boron atom to form a five or six membered ring. This phenomenon is not restricted to boron alone but is a property of many elements, and we shall have occasion later to mention the remarkable behavior of gallium.

In a rough way we can understand and sometimes predict this specificity of action between acids and bases, partly from a consideration of atomic volume and polarizability, partly from properties of rings, and partly through a study of mesomerism or resonance,[9] but for any exact formulation far more data are necessary than are now available.

Aqueous solutions afford but a small range of acid and basic strength. A really strong acid like sulfur trioxide or a really strong base like sodium nitride are almost completely hydrolyzed in water. This phenomenon, which has been called by Hantsch the "leveling effect," occurs in two stages. Since water is both an acid and a base it combines directly with any strong base or acid, and in addition hydroxide ion or hydrogen ion is set free. Just as in considering the problem of oxidation and reduction we find that we can have in water no rapid reducing agents stronger than H_2 nor any rapid oxidizing agents stronger than O_2, so in water we

[8] $B(OR)_3$ forms compounds with alkalies and also with alcoholates (Copaux, *Comp. Rend.*, 127, 721 (1898)). The boron is acting here just as it does in the widely different class of compounds between boron trialkyls and ammonia or amines.

[9] For an introduction to the idea of resonance, an idea which is becoming increasingly important in chemistry, and to which we shall have frequent occasion to refer, see Pauling's Chapter 22 in Gilman's "Organic Chemistry," John Wiley and Sons, 1938.

can have no acid stronger than H^+ and no base stronger than OH^-, except for such specific effects as have been mentioned.

Many solvents are *amphoteric* in the sense that they may serve both as acids and bases. Their molecules can therefore combine with one another and thus we explain the high degree of association in such liquids as water and alcohol, or ammonia and the primary and secondary amines. Such association disappears in the case of ethers and trialkylamines, which act only as bases.

This amphoteric character is possessed by many of our generalized strong acids. The oxygen in sulfur trioxide has extremely weak basic properties, but SO_3 is so powerful an acid that it is able to attach itself to the oxygen of another molecule, thus forming the double or continuing molecules characteristic of this class of substances. So also aluminum or ferric halides are amphoteric and when dissolved in an inert solution form double molecules, but in a solution even so weakly basic as ether they split into single molecules, which are now attached to the solvent rather than to each other.

Whenever two neutral molecules, one of which is an acid and the other a base, combine with one another, a condition of electric stress is produced, owing to the fact that the electron-pair which formerly belonged to the base alone is now shared by the two molecules. Thus a high dipole moment is set up unless it can be relieved by some molecular rearrangement. Thus when a molecule of carbon dioxide combines with a molecule of ammonia, no stable molecule would be formed were it not for the simultaneous transfer of one atom of hydrogen from nitrogen to oxygen, thus producing a molecule of carbamic acid, and relieving the electric tension.

In the acids and bases listed above, where such rearrangement is impossible, we find no compounds between the weaker acids and the weaker bases. Nevertheless, using the stronger acids or bases, an enormous number of such compounds may be formed, possessing very simple formulas in terms of electron-pair bonds. However, few of these have been described, and still fewer have been named. They are the outcasts of our present chemical system. I may call

them pseudo-salts,[10] for although incapable of ionization, they will probably be found, especially in solvents of low dielectric constant, to have properties analogous to those of an inner salt or of a true salt dissolved in the same kind of medium.[11]

THE PHENOMENOLOGICAL CRITERIA OF ACIDS AND BASES.

Since it may seem objectionable to define such important terms as acids and bases by means of our still somewhat hypothetical structures involving electron-pairs, let us attempt to ascertain from chemical behavior alone what characteristics we will ascribe to these two great classes of substances. The following traits seem to be most important.

I. When an acid and a base can combine, the process of combination, or neutralization, is a rapid one.

II. An acid or base will replace a weaker acid or base from its compounds.

III. Acids and bases may be titrated against one another by the use of substances, usually colored, known as indicators.

IV. Both acids and bases play an extremely important part in promoting chemical processes through their action as catalysts.

It will be our task to examine with respect to these criteria our generalized acids and bases and to point out the similarity, and indeed the nearly complete identity between the behavior

[10] These pseudo-salts are of the same type as amine oxide, which, indeed, falls into this class if we consider it made up of the base, trialkylamine, and the acid, atomic oxygen.

[11] Pfeiffer ("Organische Molekülverbindungen," 2nd ed., Ferdinand Enke, Stuttgart, 1927) has made a very extensive and valuable collection of the literature pertaining to compounds between organic substances and metallic salts. He shows in numerous cases the great resemblances between these and the compounds of the same organic substances with H-acids. Unfortunately, as far as I know, there has been no similar attempt to bring together the facts concerning the similar and equally important compounds between organic substances and our other generalized acids such as the oxides of sulfur and the halides of boron. Pfeiffer draws many of his conclusions from the existence and composition of solid compounds. It seems to me however that, on account of the special laws governing close-packing and stability in crystals, our ideas of molecular structure must be obtained chiefly from molecules which can be proved to exist in the gaseous or dissolved state. It remains to point out that the substances which Pfeiffer and others call *molecular compounds* are produced by the union of an acid and a base, and that the bond joining them is no different from any of the other bonds with which chemists are familiar.

of these substances and the more restricted acids and bases of common usage.

In water an acid and base neutralize one another with extreme rapidity, and also in alcohol at all temperatures down to the freezing point of this solvent. As far as I am able to observe it is true also for our whole system of generalized acids and bases. I am inclined therefore to suggest the thesis that all molecules whose electronic formulas conform to my generalized definition of acids and bases combine without impediment. In other words, that the neutralization of a primary acid and base requires no heat of activation. This behavior is the more striking in that there is only one other type of chemical reaction which can occur without activation. That is the union of an odd molecule with an odd molecule. (We need not consider here the rare case mentioned in a preceding footnote in which two molecules of opposite charge are drawn and held together by purely coulombic forces.)

Frequently the simple formula does not represent the actual state of the molecules. Sometimes, as we have seen in the discussion of amphoteric substances, the molecules partly, or even wholly, neutralize one another. More often they are neutralized by the solvent in which they are placed. They may then be said to be secondary acids or bases. For example, the base B may be dissolved in the weak acid A, and completely neutralized, in the sense that all its basic electron-pairs are now used in bond formation. If now we add another stronger acid A', the process,

$$A' + AB = A'B + A,$$

will ordinarily require activation, but the heat of activation should not be greater than the heat of formation of the compound AB. If this heat of formation does not amount to more than a few thousand calories, it is not easy to detect, and may for many purposes be ignored.

A far more interesting type of secondary acids and bases consists of those which are not acids or bases in their normal state of lowest energy, but become so through some internal excitation. Such an excitation may consist in the breaking of an existing bond. A typical case is furnished by carbon dioxide which, if represented with the double bond between

the carbon and each oxygen, or if represented by the other formulas which Pauling believes to resonate with this, always has four bonds attached to the carbon, which is therefore not acidic. In some of its excited states, however, one of these bonds may be broken. In fact it is found, experimentally, that the neutralization of carbon dioxide is a measurably slow reaction and would probably become very slow at low temperatures. Other secondary acids of the same type are substances like the organic acid chlorides and anhydrides. There is some reason for believing that sulfur dioxide also is only a secondary acid. It is stated that sulfur dioxide and ammonia do not combine as gases except in the presence of water vapor. We must be cautious in drawing such a conclusion, for in the gaseous state a reaction may fail to occur because it requires, not activation, but deactivation (as by a third body).

A substance which is neither acid nor base may become amphoteric in excited states. Thus a compound containing a double bond of the ethylene type may, when furnished sufficient energy, break a bond so that the electron-pair leaves one of the carbon atoms and belongs solely to the other. The former atom has now become a primary acid, the latter atom a primary base. This amphoteric character results often in polymerization.

Turning now to the second criterion, namely, the replacement of a weaker acid or base by a stronger one, we find just the same phenomena occurring with our generalized acids and bases as are familiar in aqueous solution, thus sodium carbonate in the presence of an aqueous acid evolves carbon dioxide. When we turn to solvents which contain no labile hydrogen the reaction is slower, owing to the small solubility of the carbonate, but I find, for example, that when finely divided Na_2CO_3 is warmed with BCl_3 or $SnCl_4$, in a mixture of equal parts of carbon tetrachloride and acetone, the carbon dioxide is soon evolved, leaving a compound which in the former case is insoluble, in the latter case soluble in the solvent. We shall find numerous examples of such replacement in our experiments with indicators, and sometimes a number of successive replacements can be shown. For example, boron trichloride, freshly dissolved in acetone, is neutralized by this

weakly basic solvent. If now a basic dye is added, this will replace the acetone, and finally a still stronger base like pyridine or a tertiary amine drives out the dye and forms its own compound with the boron trichloride.

EXPERIMENTS WITH INDICATORS.

Many chemists have carried out titrations of acids and bases with indicators in non-aqueous solvents, but they have used H-acids and usually solvents containing labile hydrogen. I have therefore carried out a large number of experiments, mostly of a qualitative character, with other members of the generalized group of acids, and in solvents whose constitution does not permit the formation of hydrogen ion or H-acids. (This is perhaps not quite true of one of the solvents employed, acetone, which has a small tendency to assume an enolic form.) I hoped by these experiments to show the changes in indicator color to be as sharp and the titrations as precise as in corresponding neutralizations in water. I was, however, unprepared for the really astonishing resemblances between the effects produced by the H-acids and the other more generalized acids. I venture to say that any one who has carried out for himself a few of these titrations will never again think of acids in the present restricted way.

I cannot describe here all these experiments, but a few of them may be summarized. First a variety of indicators were dissolved in dioxane and acetone. As bases, pyridine and triethylamine were used, and as acids, sulfur dioxide, solutions of boron trichloride and of stannic chloride in carbon tetrachloride, and silver perchlorate dissolved in benzene. The colors observed are different in different solvents. However, with one solvent and one indicator, the colors obtained seem to be dependent only upon the acid or basic condition of the solution and not at all upon the particular acid or base. The only exceptions are that with some indicators sulfur dioxide proves to be too weak an acid to give the acid color, and that sometimes one of the acids forms an insoluble precipitate [12] with the indicator, which, however, redissolves with excess of base. By means of the color changes the solutions can be

[12] Insoluble compounds between dyes and metallic salts, known as lakes, have been known and used for centuries in the dye industry.

titrated back and forth as readily as in aqueous solution. As an example, we may consider thymol blue dissolved in acetone. With both bases the color is yellow, while the acids, $AgClO_4$, SO_2, $SnCl_4$ and BCl_3, give an apparently identical bright red color.

The same red color was also obtained by HCl and this, together with the fact that none of the reagents had been especially dried, gave rise to the suspicion that some of the astonishing similarities [13] in color produced by the different acids were due to the existence of small impurities of H-acids in the reagents. For this reason the experiments were continued with a series of very dry solvents, which were kindly placed at my disposal by Dr. C. H. Li, with indicators which themselves contain no labile hydrogen, such as butter yellow, cyanin, and crystal violet. Finally a number of experiments were performed upon the vacuum bench with the assistance of Dr. G. T. Seaborg, whom I wish to thank for valuable help in these and other experiments. Such precautions were taken as to reduce the water and H-acids in the system to amounts negligible even compared with the small amount of indicator used. Nevertheless, these experiments gave results identical with those of the previous series.

Butter yellow, which is yellow in dry toluene, turns red when a minute amount of stannic chloride is added, and this is followed by the formation of a red precipitate. Upon the addition of a small amount of triethylamine the precipitate is dissolved and the original yellow color is restored. Sulfur dioxide behaves as a much weaker acid. When it is gradually added to the solution of butter yellow in toluene the solution

[13] I would have been less surprised by the identical colors produced by the several acids if I had known of the work done thirty years ago by K. H. Meyer (*Berichte deut. chem. Ges.*, **41**, 2568 (1908)). Meyer showed that the color of fuchson is the same in chloroform containing stannic chloride as in concentrated sulfuric acid. Not only is the visual color the same, but spectroscopic measurements of light absorption gave almost identical curves in the two cases. The same result was also obtained with benzaurin in the same two solutions. Meyer concluded that a molecule of stannic chloride, added to an indicator, gives a molecule which is extremely similar to one between the indicator and an H-acid. This conclusion could hardly be justified by this experiment alone, since in concentrated sulfuric acid the brilliant colors obtained with many dyes are probably due to compounds with partly dehydrated sulfuric acid, or even with SO_3.

becomes more and more red, but the full red color which would correspond to the complete neutralization of the indicator was not obtained even when the partial pressure of the sulfur dioxide reached one atmosphere.

Crystal violet is an indicator which exhibits the same colors in water and in many widely different solvents. In water, as the concentration of acid increases, the color changes from violet to green and then to yellow. It was shown in this laboratory by Rosenstein and Adams [14] that each change is due to the formation of a new substance as H^+ is added successively to the $N(CH_3)_2$ groups. When crystal violet dissolves in dry chlorobenzene it shows its characteristic violet color. With gradual addition of stannic chloride it passes through a green and then becomes yellow, after which the original violet color may be restored by an excess of triethylamine. Unless the acid is added carefully it is easy to pass through the green phase without observing it. If a similar phenomenon appeared in water we should say that the green solution exists only in a very small range of pH!

In the case of crystal violet it is not difficult to understand why the same colors are produced by different acids. In the original ion, which has an $N(CH_3)_2$ group in the para position of each benzene ring, there is resonance throughout the system of three identical rings. When one of the nitrogens, however, is neutralized by any acid, that ring is largely removed from the resonance system and we have the same conditions as in the green dye known as malachite green, which has only two para $N(CH_3)_2$ groups. When a second nitrogen is neutralized, either by H^+ or any other acid, only one ring is left in which the main resonance occurs.

Numerous indicators may be used in such solvents as we have employed that cannot be used in solvents like water. Thus triphenylmethyl chloride dissolved in chlorobenzene gives with BCl_3, $SnCl_4$, and $AgClO_4$ the bright yellow color characteristic of the triphenylmethyl cation. All that each acid does is to remove Cl^- from the indicator. In the last case silver chloride is precipitated and the color is due to the highly ionized triphenylmethyl perchlorate.

[14] Rosenstein and Adams, *J. Am. Chem. Soc.*, 36, 1452 (1914).

Work with uncommon solvents possesses not only an intrinsic interest, but often enables us to obtain a clearer understanding of aqueous solutions themselves. If an indicator is dissolved in water and the solution contains no other important acids and bases than those derived from the indicator and from the water, we may expect to find a simple monotonic relation between the color and the pH of the solution. This is what is usually assumed to be true in all cases, even in the presence of other substances which I call acids and bases. However, as soon as we become acquainted with the high specificity in the mutual action of acids and bases, we can hardly expect to find so simple a behavior. In fact, as soon as we begin to look for cases in which the pH cannot be determined directly from the color, we find them on every hand. Turmeric turns brown in the presence of borate ion and this used to be an important method of qualitative analysis. Likewise alizarin and numerous other indicators which have two basic points, so situated that they can be attached to boron to form a five or six membered ring, behave towards boric acid and borates in the same way. It is interesting to note that while in most cases various acids give the same color to a dye, this does not seem to be true if an acid forms a ring compound with the indicator. The ring undoubtedly offers new opportunities for resonance, so that sometimes the color of the ring compound is nearer to that produced by a base than it is to the color produced by an ordinary acid.

Sulfide ion, like iodide ion, acts as a strong base toward some acids. For this reason I expected to find that the color of phenolphthalein would disappear on the addition of sulfide ion. This proved to be the case. The decolorization is not instantaneous and is entirely analogous to that produced by OH^- alone at high concentration. A more interesting case of similar type has been studied by Bouchard,[15] who found that the fluorescence of fluorescein, although not greatly affected by most ions, is much diminished by I^-, and to an even greater degree by S^{--}. It is evident that a person using this indicator and unaware of these facts might make serious errors in determining the acidity of solutions.

I have found numerous cases in which the ordinary rules

[15] Bouchard, *Comp. Rend.*, **196**, 485 (1933).

for determining pH from indicator colors fail completely. I shall mention only one, which is very striking. Purpurin, in aqueous acid solutions, has a yellow color which changes through orange to a pink color at pH = 8. If, however, in acid solutions gallium chloride is added, even at so low a concentration as 0.00001 *M*, the indicator gives the pink color characteristic of alkaline solutions. In a solution containing a minute trace of gallium, a person using this indicator might make an error of five units in pH. The gallium ion seems to combine even in these dilute solutions almost quantitatively with the indicator, and probably in the ratio of three molecules of dye to one gallium. The gallium, acting as a strong acid, nevertheless, because it forms a six membered ring, gives a color aping that of a basic solution. The indicator in basic solution goes over to a more highly resonating form. The depression of this resonance by acid appears to be compensated in part by the additional resonance of the new ring.

Acid and Basic Radicals. Before leaving the subject of organic dyes, in which the optical and chemical properties are known to be markedly influenced by substitutions in the molecule, I wish to call attention briefly to an obvious and indeed necessary extension of the idea of acids and bases. We have dealt heretofore with cases in which one molecule, an acid, combines with another molecule, a base; but the same sort of neutralization may occur within a molecule. We are thus led to the idea of acid and basic radicals. Any substitution in a benzene ring may produce changes in the existing resonance of the system, but there are certain groups which have enormous effect because they are able to add new types of resonance. These are groups which can share an unbonded electron-pair with a neighboring atom and are therefore basic groups, and those which can share an electron-pair possessed by a neighboring atom and are therefore acid groups. These two classes correspond entirely to the ortho-para orienting groups and the meta orienting groups. They also correspond entirely to the auxochromes and anti-auxochromes of Wizinger.[16] The radicals NR_2 and NO_2 typify these two

[16] Wizinger, "Organische Farbstoffe," Ferd. Dümmlers, Berlin and Bonn, 1933. I have found this book a very interesting and useful description of the state of color chemistry up to the time when the idea of resonance was introduced.

classes. The former may form a double bond with an adjacent carbon atom and furnishes the necessary electron-pair. The latter may also form a double bond with an adjacent carbon atom, but the electron-pair must come from the rest of the molecule. Even though such a double bond is not wholly formed, in the sense of older structural formulas, its formation may constitute one member of a group of structures which are said to resonate with one another, and thus profoundly influences the character of the molecule.

Secondary Acids and Resonance in the Triphenylmethyl Group. Triphenylmethyl chloride in inert solvents is partly ionized, and this ionization is greatly favored by the substitution of $N(CH_3)_2$, so that crystal violet, which has one of these groups in each para position, behaves as a typical strong salt in aqueous solution. The ion is amphoteric in that it may act as a primary base and as a secondary acid. In the presence of acid, hydrogen ion adds instantly to the basic nitrogen until equilibrium is established. On the other hand, the addition of hydroxide ion to the central carbon, which is the process that causes bleaching in strong alkali, is slow and requires, according to the measurements of Biddle and Porter,[17] an activation energy of 14,000 calories. An entirely similar process occurs in the bleaching of phenolphthalein by OH^- and S^{--}, which we have just discussed.

Wizinger states that triphenylmethyl chloride, which dissolves in chlorobenzene to give a pale yellow solution, turns a bright yellow, owing to ionization, when heated to the boiling point of the solvent, and that it returns to its original color on cooling. I have repeated this experiment and find that when the boiling solution is cooled it does not return at once to the original pale color. In fact, if the boiling solution is rapidly chilled, it may be kept for hours at the temperature of ice, without appreciable loss of color. All these facts show that the plain and substituted triphenylmethyl cations are, not primary, but secondary acids.

In the formulation given by Pauling for the possibility of "resonance between two or more Lewis formulas," he shows that it is not only necessary that the energies of the several forms be nearly alike in order to make the resonance signifi-

[17] Biddle and Porter, *J. Am. Chem. Soc.*, **37**, 1571 (1915).

cant, but also that the several formulas must belong to what may be called the same quantum type.[18] However it is evident that in complex molecules the question as to whether two formulas belong to the same type can hardly be settled by the few rules which have satisfactorily interpreted simple atomic spectroscopy. Instead it may be necessary for some time to obtain such information empirically from observations of chemical behavior.

It seems obvious that resonance could not occur between a paramagnetic and a diamagnetic form. It seems also unlikely that resonance can exist between two formulas, one of which contains odd electrons and the other only paired electrons. Thus it seems to me that the one-electron bond formulas for B_2H_6, discussed by Sidgwick and by Pauling, cannot be included in the resonance system characteristic of this substance in its normal state. What further restrictions are to be placed upon the kind of structures which may resonate with one another? I should like to suggest tentatively, and as a subject of further investigation, that, at least in the triphenylmethyl series, there is no resonance between the formulas corresponding to a primary acid and those corresponding to a secondary acid.

If we consider the triphenylmethyl cation and its various derivatives we formerly had to choose between formulas which could be indicated by

$$-\overset{|}{C}- \text{ (I)} \qquad \text{and} \qquad -\overset{|}{C}= \text{ (II)},$$

where I shows trivalent carbon and the positive charge situated in the neighborhood of this central carbon, while II shows a quinoid form with the positive charge transferred to some other part of the molecule. In terms of present theory, I represents a group of resonance terms, while II represents a much larger group, for the double bond may belong to any one of the three rings and in that ring both ortho and para quinoid formulas are possible. Now my contention is that there is no resonance at all between the formulas of group I and the formulas of group II, and that the resonating system II must suffer an excitation before it can go over to the system I.

[18] Pauling, *J. Am. Chem. Soc.*, **54**, 988 (1932).

A further experimental study of reaction velocities in such systems will be interesting.

ACIDS AND BASES AS CATALYSTS.

It has been pointed out that in aqueous solutions we can study only a small part of the range of acid and basic strengths. So we find that in water, while acids and bases show pronounced catalytic effects, they usually only accelerate reactions which occur to some extent without catalysis. When we turn to the stronger acids of our generalized system we find that they are capable of producing a great number of reactions which could not conceivably occur without their intervention. When we consider the various organic syntheses that are caused by strong acids such as the halides of many metals and of boron, we see more fully the scope of catalytic action. It is true that in many cases the substance which promotes the reaction is used up during its course, but there are many cases in which these substances act as true catalysts.

In this vast field almost no quantitative measurements of reaction velocities have been made, but some qualitative observations are pertinent to our purpose. We have seen that I^- and SCN^- act as strong bases towards SO_2. It is interesting therefore to recall some observations of Rosenheim.[19] He found that sulfur dioxide reacts with sodium ethylate in alcohol solution to give the ion $ROSO_2^-$, which can then go over to the sulfonate ion, RSO_3^-. This reaction is specifically catalyzed by I^- and CNS^-. This is evidently a clear case of basic catalysis, due to the formation of temporary intermediates between $ROSO_2^-$ and the basic ions.

When we turn to the consideration of aqueous solutions we may expect to find many similar instances of large specific catalytic action by various acids and bases. Such a phenomenon has not yet been found. It has long been accepted that reactions are promoted by hydrogen ion and by undissociated H-acids, and that the effectiveness of H-acids toward all reactions is a simple monotonic function of their acid strengths. This conclusion has seemed to be confirmed by a great deal of careful work on the part of Brönsted and his associates. Yet

[19] Rosenheim, *Berichte deut. chem. Ges.*, **31**, 405 (1898) and **38**, 1303 (1905).

from the ideas developed in this paper we must judge such a conclusion to be entirely erroneous. The reason that specific strong catalysis by certain acids and bases has not been observed is not far to seek. If we look at the reactions summarized by Schwab [20] we see that all the reactions which have been studied and used in support of the monotonic hypothesis have been reactions that involve hydrolysis, the addition of water to a molecule, the subtraction of water from a molecule, or the transfer of labile hydrogen from one part of the molecule to another. As soon as reactions of a quite different type have been carefully studied in water and in other solvents, we may look for wide departures from the rule that acids and bases can be arranged in a definite order with respect to strength.

[20] Schwab, "Catalysis." English translation by Taylor and Spence. Van Nostrand, New York, 1937.

ELECTRICITY AS A FLUID.*

BY

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As all the world knows, Benjamin Franklin was one of the great early figures in electrical research and, in particular, established the electrical nature of lightning by his celebrated kite experiments. In the course of these investigations he was led to conjecture that electricity is a kind of fluid. More precisely he thought of a positively charged body as carrying more of this electrical fluid than a negatively charged body. Thus the neutral condition arises when electricity is equally distributed in material bodies. Such a one-fluid theory has an obvious disadvantage: since electricity of one sign repels itself, there should be a force of repulsion between the parts of any body carrying a charge, and no such repulsion is found in the neutral state.

Franklin's investigations of the nature of electricity formed, of course, one of the instances of his remarkable versatility; and it is interesting for a mathematician like myself to recall his ingenuity in devising magic squares, showing that he was not only curious about the laws of Nature, but also about the fascinating properties of numbers.

The theory of electricity which I propose to describe today is a two-fluid theory and yet resembles in a certain sense the one-fluid theory of Franklin more than it does the final form of the two-fluid theory which held sway until the beginning of the present century. In fact according to the theory offered here positive and negative electricity may freely interpenetrate to produce a true neutral condition. According to the usual two-fluid theory, however, elementary positive and negative electrical particles cannot interpenetrate, so that a true neutral condition is impossible.

The subject of my talk will appear out of date to most physicists. For this reason I must begin by indicating a few

* Presented Friday morning, May 20, 1938.

of the considerations which have interested me in it. Roughly speaking, until about the year 1900 a background of absolute time and of space filled with an electro-magnetic ether, together with continuously distributed electrified matter, formed the basis of attempts to explain physical phenomena. In this effort free use was made of such conceptual models as rigid, fluid, and elastic bodies.

It was realized by the end of the last century, however, that there was something essentially inappropriate in the use of such models; and the new era of special relativity opened by the work of Lorentz and Einstein showed why this was the case. But there were certain attendant disadvantages. In particular the concept of a rigid atom carrying an electric charge and yet obviously stable, had to be abandoned since no relativistic substitute for the rigid body was found. Thus through relativistic advances there arose a general scepticism as to the validity of previous concepts concerning matter, and physicists were led to conjecture that all mass was electro-magnetic.

Meanwhile the famous quantum hypothesis had been enunciated by Planck in 1900. According to him, energy was radiated from the atom only in discrete quantities or quanta, and not continuously as had been thought. This hypothesis led to the formulation of the so-called Einstein radiation law by Einstein in 1905 and to the Bohr theory of the atom in 1913. In this last theory the protons and electrons were thought of as point masses carrying electrical charges $+e$ and $-e$, the light electron rotating around the heavy proton in an elliptical orbit due to the forces of electrical attraction. Bohr's startling *ad hoc* hypothesis that the electrons can jump discontinuously from one stationary state to another, contributed to make the notions of space, time, and matter more insubstantial than ever.

Then came the present theory of quantum mechanics beginning with Heisenberg's and Schrödinger's celebrated work of 1926. Although Schrödinger's theory takes its start in the usual model of the atomic system, this is finally discarded as a kind of preliminary scaffolding. It is only the final Schrödinger equation, determining the energy levels and so the atomic frequencies, which is regarded as fundamental.

What has been the consequence of this theory? Simply that somehow or other the mathematical physicist has constructed a remarkable bridge which enables him to pass from a classical picture of the atomic system to highly accurate formulæ for the positions and intensities of the spectral lines of the chemical elements. Thus it has become possible at last to describe spectroscopic phenomena and to branch out into related fields. Inasmuch as physicists have long regarded the spectra of the various elements as affording the true key to atomic structure, it is easy to understand why the opinion gained currency that the ultimate secret of atomic structure was about to be revealed.

A decade has gone by, however, and much of this first optimism has disappeared. Many physicists would concede today that theoretical physics is in need of basic revision. One reason is that many of the hypotheses which have been employed in the development of quantum mechanics seem *ad hoc*. In my opinion, the present state of quantum mechanics is somewhat analogous to that of theoretical astronomy after Kepler had successfully described the motion of two bodies. It would have been possible then to arrive at the details of lunar and planetary motions as arising from a slight disturbance of Keplerian motions. These disturbances obviously involve the fundamental periods of the constituent two-body problems, such as the solar year, the lunar month, etc. Then by use of suitable "selection rules" and similar devices, I feel confident one could arrive at a fairly satisfactory descriptive theory. Very fortunately, however, Newton formulated his law of universal gravitation and so rendered tentative mathematical work of this sort unnecessary. Perhaps some similar new conceptual outlook will shortly replace the present abstract and artificial point of view of quantum mechanics.

May it not be that the full exploitation of relativistic electro-dynamics will reveal possibilities which have been overlooked? This is a field which has never been investigated adequately, because the successes of Planck and Bohr convinced the physicists that the universe about us is as discontinuous in its essence as the set of positive integers. In other words there has ensued a state of mind prejudiced against the

use of continuous space and time as fundamental instruments of thought. One can scarcely help recalling similar decisions of the past, first in favor of Newton's corpuscular theory of light, then in favor of the alternative wave theory—both of these being now replaced by an uncertain combination of the two theories which is adopted with almost no dissenting voice.

Whether or not relativistic electro-dynamics will ultimately play a fundamental role is highly conjectural. But I feel confident that a systematic study of this neglected field needs to be made, if it serves only to establish the true limitations of the conceptual models which it furnishes us. If the attempt to use such means fails, I know of no other possibility for a conceptual understanding of the physical universe.

Immediately after the first formulations of the new quantum mechanics I presented in 1926 a first attempt of this kind before the American Association for the Advancement of Science at its Pittsburgh meeting. What I wish to talk about today is a somewhat improved theory which was given by me before the International Congress for Mathematicians at Oslo in 1936, although I have not been able as yet to work out all the details in satisfactory form.

In this theory my first remark is one which concerns the role of gravitation, namely that gravitational effects may be omitted entirely from consideration. In fact if but little matter is present in space-time, gravitational forces become practically negligible and the relativistic background becomes that of the flat space-time used in the special theory of relativity. Now if one writes down the laws of motion for such a universe, inclusive of the electro-dynamical equations, and interprets the rectangular coördinates used as "geodesic coördinates" in the generalized theory of relativity, one arrives at modified laws in which gravitation is basically incorporated. In other words we can omit or include gravitational effects with the same facility as in the Newtonian theory of gravitation where gravitational forces are merely superadded. We are, therefore, justified in confining attention to the space-time of the special theory of relativity.

Let us now suppose a continuous distribution of inchoate matter having a density ρ. Such a distribution would be

approximately realized by a cloud of cold nebular dust remote from all other matter. For such an over-simplified universe a complete mathematical theory is possible; and to a first approximation the final result may be stated in the form that each particle travels with uniform velocity in a straight line except as deflected by the usual gravitational forces of attraction exerted by the other particles.

An interesting extension of this model is obtained if we imagine positive or negative electrical fluid of density σ to be attached to such inchoate matter. But I do not know of any physical situation in which a universe of this kind might be approximately realized in ordinary experience. Adjacent portions of such charged matter would be mutually repelled by enormous forces of electrical origin and so would tend to recede from one another at high velocities. On the other hand, there would be a strong tendency for oppositely charged portions to approach one another due to attractive forces and to become neutralized by super-position. Thus there would soon be attained a nearly neutral state much like that of uncharged inchoate matter. Here too the mathematical theory would be complete, although the classical electrodynamic equations of Maxwell and Lorentz now come into play.

This seems to be about as far as we can go without introducing "non-electrical forces." Three or four years ago I should have felt somewhat embarrassed to introduce such forces, but today physicists are once more admitting that such forces need to be used in order to account for the observed facts. At a meeting of the American Philosophical Society recently held in this city, Dr. Karl Darrow has alluded to this change in attitude. *A propos* of this, I may remark that it has always seemed to me impossible to develop logically the fundamental equations of the electro-magnetic field except by taking in from the outset ideas of pondero-motive force, of space-time, of mass, etc.

Let us, therefore, search for a generalization of the notion of the rigid body, the elastic body or the fluid which is appropriate to the special theory of relativity and which is as simple as possible. Up to the present time no one has found a satisfactory generalization of the rigid or elastic body. The

reason for this failure is obvious. In both cases we have a natural shape of the body when its parts are relatively at rest. The possibility of such a natural shape arises through the fact that tensional forces may be introduced which change as the Euclidean distance of nearby points changes. But in special relativity, distance in the ordinary sense has lost its meaning; for example, the space-time distance between a point emitting light and a point on the out-going light wave a thousand years later is still zero. Our only chance, therefore, turns out to be a generalization of the adiabatic fluid, which can be easily accomplished as follows. Let us imagine again a continuous distribution of matter of density ρ; but let us suppose that such matter is subjected to a certain body pressure p which is functionally related to the density, $p = f(\rho)$. In such a fluid the parts would tend to move as in the case of inchoate matter except insofar as the pressure gradient yields additional body forces. Such a relativistic fluid is used by Lemaitre in his theory of the expanding universe. Mathematically speaking, this is a very natural generalization, in that the energy tensor $T^{ij} = \rho v^i v^j$ of inchoate matter is replaced by

$$T^{ij} = \rho v^i v^j - p g^{ij};$$

here v^i is the velocity tensor of matter and g^{ij} is the fundamental gravitational tensor in contravariant form. We are assuming for the moment that the fluid carries no electric charge.

And now I must mention a routine of technique which is fundamental for me in such mathematical model-making: I try systematically to avoid various theoretic difficulties which have arisen in the past. A particular difficulty of this kind for an adiabatic fluid is the following. Such a fluid has a natural disturbance velocity analogous to the velocity of sound in a gas. Now if one were to constrain a rigid body immersed in a gas to move suddenly in any direction at a velocity greater than that of sound the ordinary mathematical theory would break down. A similar state of affairs holds in our relativistic fluid. More precisely, if two parts of the fluid collide with a relative velocity more than twice the disturbance velocity, the theory fails. Consequently we get into difficulty unless the disturbance velocity of the fluid is at least as great as that of

the maximum velocity of the body as a whole, namely the limiting velocity of light. On the other hand, it would seem absurd to suppose that the disturbance velocity can exceed that of light. Thus the demands imposed by the mathematical point of view seem to require that the disturbance velocity is always that of light. This leads to the conclusion that the fluid in question must be what I have called the "perfect fluid," with constitutive equation $p = \frac{1}{2}(\rho - \rho_0)$ where ρ_0 is the density under no pressure. Here the units of length and time are taken as the light-second and the second respectively.

A neutral portion of such a perfect fluid tends to expand when its density is greater than that of the natural density ρ_0, and it tends to contract in the contrary case. As time elapses the fluid would tend to assume a highly irregular fluctuating shape, wisp-like but with finite total volume. If considerable masses of the fluid were contained in relatively small volumes, gravitational forces would enter and the bodies might take an approximately spherical form and move in various orbits through space. It is clear that this affords an interesting model from the astronomical point of view.

From now on we shall use such a perfect fluid as a carrier of electricity and will suppose that the electric fluid of density σ is attached to this form of matter. If σ is positive, such matter is positively charged; if σ is negative, it is negatively charged; and if σ vanishes the matter is neutral. We envisage first the case in which the electrical charge is everywhere of one sign. According to the electro-magnetic equations the total quantity of electricity can never change; from which it results that the ratio of ρ to σ^2 is a constant along the world-line of any particle of our fluid; this corresponds to the fact that the natural mass of any part of the perfect fluid will not be strictly invariable. This ratio φ is called the substance coefficient.

In such a universe matter would tend to expand indefinitely due to enormous electrical forces of repulsion, but nevertheless the total volume would remain finite. There would take place a rapid dispersal of the electrified matter throughout space, so that the parts recede from one another in wisp-like forms. If distinct portions of the fluid happen to collide at

any velocity (less than that of light) no mathematical difficulty arises due to the extraordinarily resilient character of the fluid alluded to above. However, in order to make the theory absolutely complete, definite laws would have to be formulated as to what happens after collision. For instance the bodies might separate again freely when the tension reduces to zero; or might stick together permanently as a unitary fluid; or might act in an intermediate manner. For the moment we omit formulation of such laws of contact.

When we suppose that positively and negatively charged matter, and even uncharged matter, are present, the situation is somewhat more complicated. If we adhere to Franklin's notion that electricity can be uniformly distributed in space, we must admit the free interpenetration of positively and negatively charged matter. For the moment we do not specify any other rules governing the behavior of bodies which come into contact. In such a universe it is clear that positively and negatively charged portions of matter would tend to become superimposed so as to neutralize electric charges. Furthermore, until such neutralization is effected electromagnetic radiation of energy into space will continue. However, the resulting final neutral condition would seem to be entirely amorphous. Our next step, therefore, is directed towards securing something like a stable atom.

In order to achieve this goal, I again generalize the perfect fluid by assuming that there exists certain further body forces, attributable to what I have called an "atomic potential," ψ. These are forces which constantly act in the direction of the gradient of ψ, being proportional to this gradient. The atomic potential itself is given once for all at each point of the body. Mathematically speaking, this generalization amounts to replacing the energy tensor written above by

$$T^{ij} = \rho v^i v^j - (\tfrac{1}{2}(\rho - \rho_0) - \psi) g^{ij}.$$

We have now specified the complete list of constitutive equations for the electrified fluid in space-time.

It remains to determine the arbitrary functions at our disposal. These are the substance coefficients and the electrical densities which are regarded as given primordially. Following what is usually attempted in physics, it seems best

to begin by specifying these functions for the hydrogen atom in static neutral condition. When this state of equilibrium is disturbed it is then to be expected that some kind of radiation of energy will take place and our guide in determining the nature of the functions at our disposal is that the radiation frequencies should be those called for by the known spectroscopic facts. Our first supposition will be that in a static neutral state we have spherical symmetry with the same constant electric density $\pm k$ throughout the proton and superposed electron. All that remains to be specified is a single arbitrary function of the radial distance. Our special hypothesis is then that the squared substance coefficients and atomic potentials (which are all in fixed constant ratios to one another) are given by the reciprocal of a quadratic expression in $1/r$ where r denotes radial distance. This turns out to yield a theory with the same arbitrary physical constants as are required by current theories, namely the masses of proton and electron, the electronic charge and Planck's constant h.

Of course the vibrational frequencies of such a hypothetical hydrogen atom can be computed by well-known methods. In order to obtain the desired frequencies of omission, an artificial use had to be made of the Planck radiation law. When I proposed my theory of 1926, I saw that this was the case, but gave out the theory notwithstanding.

It appears to me an extraordinary fact that closer examination has shown other lower, secondary frequencies to be present of precisely the type demanded by the Planck radiation law, although it is not yet clear that these will be dominant for relatively large disturbances of the atom. Such frequencies arise naturally here, precisely because we have to do with non-linear wave-equations. On the other hand, such difference frequencies cannot arise naturally if we employ the fundamental Schrödinger equation, inasmuch as it is strictly linear. Furthermore the correct fine-structure formula can also be obtained, although certain difficulties of interpretation have yet to be overcome. What needs especially to be investigated is whether or not the energy of such secondary radiation obeys the Planck radiation law. The mathematical situation involved is quite complicated, but I hope to complete the necessary calculations at an early date.

There are two serious objections to this model of the hydrogen atom. T. L. Smith[1] showed in 1928 that such an atom would be essentially shapeless except for the feeble influence of gravitation tending towards the spherical form; furthermore he pointed out that the small oscillations could not all be stable. In consequence I have added a further rule requiring convexity at the outer surfaces of the proton and electron, as well as at the "mechanical surface" of the proton where interpenetrability with other protons is supposed to cease; the mechanical surface is taken to be at the Bohr radius. This means that when the surfaces in question are about to lose their convexity, body forces normal to the surface come into play which prevent any concavity.

Because of this additional law of convexity, it is apparent that the proton, whose volume always remains limited, can only extend itself in space by assuming a needle-like or disc-like form. It is obvious that neither form can be maintained under a succession of accidental collisions so that a return to approximately spherical shape may be expected. It would, therefore, seem that such a law of convexity will go a long way toward securing the desired atomic stability.

Similar provisions can readily be made to obtain other elementary particles such as positrons, neutrons and photons, and to insure their agglomeration into more complicated types of atoms. To this end, it may, for example, be supposed that a proton and neutron in contact will not separate until a certain critical tension $\rho_0/2$ is reached. Inasmuch as this part of the theory is as yet highly problematical, I shall not allude to it further, except to stress the fact that many possibilities are at our disposal.

My chief aim then today has been to urge the importance of further thorough-going consideration of relativistic electrodynamics. The special study which I have described above was built in consonance with certain purely mathematical necessities on the one hand, and qualitative physical considerations on the other. Although I propose to work out the consequences of my theory as rapidly as possible, I regard it merely as paving the way for other similar and probably more

[1] See his Doctoral Thesis, "The Birkhoff Fluid Theory of Electricity," Harvard University, 1928.

successful mathematical experiments. Unfortunately, such work is not likely to be particularly appealing to the theoretical physicists of the present day who would abrogate ordinary physical intuition. This seems to me to be unfortunate.

In fact if ordinary physical intuition is to be permanently relegated to an inferior position, we must think of the objective universe as presenting to our senses an entirely false conceptual facade beyond which is vaguely to be discerned the one true *sanctum sanctorum* of quantum mechanics. Let us hope that this is not really the case and that our every day common sense ideas may continue to hold a fundamental place among the things of the mind, having long been one of our most cherished possessions. I am sure that the great and realistically minded Benjamin Franklin, whom we unite to honor here, would have wished to retain permanently such ideas in their most valid form and to utilize them to the utmost.

INFLUENCE OF ASTRONOMY ON SCIENCE.*

BY

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Many arts and sciences have contributed to the exploration of the celestial regions. Reciprocally the heavens have illuminated and are illuminating many of the sciences that pertain to the earth, for our planet has been found to be only a particle in a universe of matter, its life only an incident in the history of the cosmos, and terrestrial phenomena and laws only particular examples of universal events and principles.

What is the foundation on which all science rests? It is what we think of as the orderliness of the universe, the regularities in the sequences of its phenomena. Without orderliness there could be no science, for unless there were a firm conviction that nature is orderly there would be no attempt to discover its order. In this age of science it is difficult to realize that in ancient times men almost universally believed that the physical universe is subject to the whims of capricious gods and goddesses. Then chaos prevailed on the earth and in the heavens above; superstitions cast their terrifying shadows over mankind. But before the dawn of recorded history regularities in such phenomena as the recurring seasons and the phases of the moon had been noted. Even before the time of Aristotle, in the fourth century B.C., the lengths of the month and the year had been measured to within a minute or two, the inclination of the plane of the earth's equator to the plane of its orbit had been determined with considerable accuracy, the causes of eclipses of the sun and of the moon had been discovered, and much progress had been made in developing theories of cycles and epicycles for explaining the apparent motions of the sun, the moon and the planets among the stars. All these great results, depending upon centuries of observations, had been established

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before any considerable steps had been taken in the development of the sciences that pertain only to things on the earth. It is to the glory of astronomy that in it men thus first perceived that the universe is orderly and entered on the pathway to science.

It may be surprising that order should have been first clearly perceived in phenomena presented by distant things. But distance smooths to imperceptibility the countless little ripples of phenomena which would confuse us with their complexities were we among them, and leaves to our perceptions only the regularly recurring great waves which roll along like the swells of the ocean. Though the moon has more than a thousand measurable cycles in its motion, a few determine all the important characteristics in the succession of its phases. In ever-changing shape, it courses through the night sky when all the distractions of the day are covered by darkness. Inaccessible and somewhat mysterious and with cycles of change short enough to be held easily in the memory, it attracts the attention and makes clear the orderly succession of its phenomena.

One of the principal methods in the development of science is generalization. If the motions of the moon are orderly, then why not the motions of those mysterious wanderers among the stars, the planets? Thus the ancients must have asked themselves the question. Since the planets revolve around the sun instead of around the earth, their apparent motions as observed from this rotating and revolving planet are enormously more complex than those of the moon. Yet long series of observations and endless calculations had led to the discovery of the order in them by the beginning of our era. All who have read the Almagest of Claudius Ptolemy, which was published about 1800 years ago, have been amazed at his knowledge of the apparent motions of the planets, and at the perfection of his theories for explaining them. In only a few other sciences have similar very close correspondences between theories and observed phenomena been reached even at the present day.

The words "order" and "orderliness" have been used as though they have perfectly definite meanings which are generally understood. But we find on examination that it is

difficult if not impossible to define them, and that it is equally difficult to determine whether natural phenomena are orderly according to any definition that we may adopt. It does not relieve us to say that phenomena are orderly when they obey laws that we can state, for essentially "laws of nature" are only descriptions of phenomena, often in time sequences. There is nothing of compulsion or causality in laws of nature, for they are man-made—and often man-destroyed—formulations of how certain classes of things exist or occur. Consequently, if there is any definite content in such a phrase as a "law of nature" it belongs to a description, whether in words or symbols, that scientists themselves have invented.

Now what properties of a description entitle us to say that the phenomena it describes are orderly? A ready answer would be that the description is simple. But what is simple depends to a large extent upon the information and experience of the person considering it. It depends also upon the terminology or notation in which it is expressed. For example, the unperturbed motion of the earth around the sun is simple to one familiar with the properties of conic sections, but enormously complicated to one who does not have such knowledge. Or, as to notation, explicit formulas describing the complicated motions of the moon fill many pages, but the differential equations which contain implicitly everything pertaining to its motion may be written on a calling card. Simplicity of a description, therefore, does not appear to be a satisfactory criterion for determining whether the phenomena it describes are orderly, for simplicity depends in considerable part upon considerations that are entirely independent of the things described.

Another possible criterion of orderliness of phenomena is whether or not they are cyclical in character. Most of the phenomena with which we are generally familiar are approximately cyclical. Not only do day and night and the seasons endlessly recur, but there are fundamental rhythms in our own lives—the beatings of our hearts, the inhalations and exhalations of our lungs, our periods of activity and repose, the electric potentials that rise and fall in our brains. But phenomena do not exactly repeat themselves. No day ever exactly duplicated another day, no two seasons were ever

exactly alike. Although strict periodicity in nature is never found, the approximately cyclical character of phenomena appears to have been fundamental in the origin and development of science, and to be fundamental for its progress. Indeed, without repetitions our memories would appear to play only with dreams and our reason would grope in vain for materials for its use. That is, the experiences which are basic in the evolution and exercise of our mental processes are cyclical in character. In general, we feel that we understand phenomena only when we analyze them into series of nearly repeating elementary events. When we have succeeded in such an analysis, we regard the phenomena as orderly, and we are satisfied.

Science was born in astronomy because many celestial phenomena are compounded of relatively few cycles. It flourished long in this science before there were comparable developments in other fields both because of the simplicity of its repetitions and because of the amazing successes of its predictions. For many centuries it alone filled the reason, as well as the imagination, with awe.

Throughout the history of science there have been attempts to discover the *causes* of phenomena instead of simply *how* phenomena occur. To account for the motions of the planets the Greeks invented crystalline spheres, apparently not realizing that if they felt impelled to ascribe causes they should explain also both the crystalline spheres and the reason for their rotation. A parallel case was the invention of the luminiferous ether to carry the transverse waves of radiant energy. These fictitious causes or instruments are in the nature of anthropomorphisms, having their origin in our feeling that by acts of our wills we cause phenomena to occur. In very ancient times men were a little more naive, inventing gods and goddesses as the causes of phenomena. Fundamentally the gods and goddesses of antiquity and the crystalline spheres and ethers of more recent times are alike. All have been introduced arbitrarily in order to make the phenomena of the physical world parallel what we regard as the consequences of our own volitions.

Now and then newly discovered facts or phenomena have compelled the abandonment of irrelevant scaffoldings in our

science. Perhaps the earliest clear example was Kepler's derivation from observations of the three laws of planetary motion which he announced more than three hundred years ago. The demonstrated elliptical motions of the planets around the sun at variable angular rates made it impossible to retain as realities the fantastic crystalline spheres of the Greeks. And, similarly, the fact that radiant energy has the properties of both waves and particles eliminates the assumption of a luminiferous ether.

It is remarkable that the history of the theories of the motions of the planets has not had a greater influence on later ideas respecting the essential meaning of "laws of nature." Over and over again, even in astronomy, analogues of the crystalline spheres of the Greeks have been introduced in order to have causes of phenomena, although all we know is the relationships among the phenomena themselves.

One of the greatest and most important changes in point of view in science occurred with the acceptance of the heliocentric theory of the solar system. Although Aristarchus of Samos, three hundred years before the Christian Era, clearly formulated the theory that the earth rotates and revolves around the sun, and explained by it the seasons and all the apparent motions of the heavenly bodies, the earth was almost universally believed to be the center of the universe until the time of Copernicus near the middle of the sixteenth century. In spite of his painstaking and convincing comparisons of theory with observations, the heliocentric theory was not generally accepted even by scientists until after the time of Galileo, a century later. Then the solid earth beneath, contrary to accepted common sense, philosophy and theology, suddenly became a spinning particle flying unsupported in the immensity of space. Man found himself removed from his proud position at the center of the universe to the surface of one of its lesser constituents. As vague fears entered his heart that he might not be the principal object of creation, he naturally resented the new and subversive doctrine.

Another reason that the revolution of the earth about the sun was at first difficult to accept was that there was nothing assigned to support it or to cause it to move. This psychological defect in the theory was partly remedied by the dis-

covery of the laws of motion and the law of gravitation, which were regarded as the cause of the motions of the planets and their satellites. Although this cause was a rather intangible set of formulae, it gradually acquired reality in the minds of scientists, as abstract ideas always do with increasing familiarity.

With the formulation of the laws of motion and the discovery of the law of gravitation by Newton, physical science closed a long period, extending from the prehistoric days when men first began to perceive that there is order in the motions of the heavenly bodies down through the centuries of painstaking observations to the time when Kepler laboriously worked out his three laws of planetary motion. With the publication of Newton's Principia in 1687, physical science entered on a new and glorious period. The transition from the old to the new was sudden, and the completeness of the revolution in point of view has perhaps never been equalled in science or in any other field of human endeavor.

Previous to the work of Newton descriptions of phenomena had been made by means of tables of values or geometrical constructions or kinematical models. All at once something entirely new was introduced, derivatives of the first and the second orders. With all the background of knowledge and experience we have now, it is difficult for us to realize the revolutionary nature of the new concepts and methods. Let us cast out from our minds Newton's work and think of the problem of describing the path of a projectile in a vacuum. From experience we know that at each instant it has a definite distance and altitude; consequently we can make a table for its coordinates. If we desire its components of velocity we can make a similar table. We can make a diagram of its path and mark off on it intervals of time. The table or the diagram is fairly descriptive of the phenomena—in few fields of science do we have more. But the equations of Newton are universal, containing implicitly complete descriptions of all properties of the motion not only at the surface of the earth but at any other place.

Dynamics originated largely in connection with the problem of explaining the motions of the moon and of the planets, though Galileo had previously gone far in his investi-

gations of the motions of falling bodies. Fortunately the masses of the planets are so small relative to the mass of the sun that each of them moves, at least for several revolutions, almost as though the others do not exist. If it were not for this circumstance, there would not have been any simple laws of planetary motion for Kepler to discover. Without Kepler's laws, Newton could not have verified his theories of the laws of motion and of the law of gravitation. Without the work of Newton or similar work, dynamics would not have been founded and the progress of all science would have been much slower.

Of equal importance in the founding and verifying of the principles of dynamics was the fact that the sun affects the motions of the moon, and the planets interact upon one another; for these perturbations, as they are called, are the consequences of foreign influences which would be most likely to produce unexpected results if any of the laws from which they are derived were erroneous. Newton himself made more verifications of the principles he laid down than have been made even today for almost any other law in the whole domain of science. His successors, particularly Lagrange, Laplace and Euler, extended the agreements between theory and observations to thousands. Some of these verifications of theory were of the most involved nature, consisting of a series of consequences, each of which in turn became the cause of other perturbations. For example, the attraction of the sun slightly increases the period of revolution of the moon, the amount depending upon the dimensions and shape of the orbit of the earth. The planets are slowly altering the shape of the orbit of the earth, with the result that the effects of the sun on the orbit of the moon also gradually are changed. Although the cycle of these slight effects are thousands of centuries in length, Laplace worked out all the complicated interactions of forces and obtained theoretical results which were precisely verified by observations.

It was not of much practical importance in every day matters that Laplace showed that the gravitational interactions of the bodies of the solar system are in harmony, even to many decimals, with the implications of theory.

But these amazing demonstrations of the exactness of the law of gravitation were made in the infancy of, or before the birth of, most of the sciences and scientific theories of the present day—a generation before Dalton's founding of the atomic theory of matter, two generations before Wöhler's first synthesis of an organic compound and Faraday's experiments on the relation between electricity and magnetism, three generations before Joule's and Mayer's formulation of the law of the conservation of energy and Darwin's work on the origin of species, more than a century before chemists and physicists first penetrated into the subatomic world or astronomers had made substantial progress in exploring our galaxy of stars. Even to this day there are no more striking illustrations than the motions of the planets and their satellites that the universe is orderly.

The indirect effects of the triumphs of celestial mechanics during the eighteenth century were the important ones. Whenever in later times chemists were tempted to despair of explaining chemical processes or geologists were assuming creation and cataclysms or biologists were appealing to mysterious vital forces, there arose always before them the shining example of perfect order and comprehensibility in the motions of the heavenly bodies. Whenever scientists or philosophers were inclined to take a narrow view of the cosmos in space or in time, the limitations they were about to impose were contradicted by the immensities of the celestial spaces and the long cycles in the motions of the planets.

It is universally agreed that evolution is one of the most important concepts in science. In a sense it completes science. As has been stated, the basis on which science rests is the orderliness of the universe, and orderliness is essentially the approximately cyclical character of phenomena. But phenomena are not exactly repeated. For example, the cycles of the moon's motion do not exactly recur, nor do the waves on the sea or the characteristics of living organisms. Evolution provides for these continual variations; indeed, it depends on them. The departures from cyclical repetitions of phenomena are not discontinuous or relatively large. They are rather in the nature of slight modifications in the cycles that we regard as essential to order. But when variations occur on the

whole in one direction over long periods of time, as they may, the changes eventually become very great. So the fundamental basis of science as enlarged and enriched by the principle of evolution provides us with a universe that is orderly in a limited sense and not essentially unchanging.

Although evolution was adumbrated in the writings of the Greek philosophers, it could not take definite scientific form until recent times. It found its first clear expression in astronomy about a century before Darwin published his "Origin of Species." Curiously it appeared independently in three countries; in England in 1750, in a book by Thomas Wright; in Germany, in 1755, in a brilliant volume by Emmanuel Kant; and in France, in 1796, as a chapter in a general survey of astronomy with which Laplace followed the publication of his monumental *Mécanique Céleste*. Each of these writers attempted to trace out the evolution of the solar system on the basis of the principles of mechanics.

Of the three theories of planetary evolution, that of Laplace had by far the greatest influence, partly because of the great name of its author, partly because of its relative simplicity and partly because the scientific world was gradually being prepared for such revolutionary ideas. The nebular hypothesis of Laplace, as it was called, gradually became widely accepted in science. It pointed to a long history for the earth and undoubtedly had an important influence in the struggle among geologists over Catastrophysm and Uniformitarianism in the early decades of the nineteenth century. It accustomed scientists to thinking of change in long periods of time and thus prepared the way psychologically for the theory of organic evolution. It affected the philosophy of Spencer and its influence extended even to theology. By the beginning of the twentieth it had tinged the thoughts of all the world.

Since all our knowledge of celestial bodies is obtained from the radiant energy we receive from them, astronomers from the time of Galileo have been interested in the properties of light. About 1608 Jan Lippershey used the property of the refraction of light in designing spectacles. Upon hearing of this work, Galileo at once invented the refracting telescope and with it observed craters on the moon, the largest four

satellites of Jupiter and spots on the sun. For different reasons each of these discoveries was of great interest and importance. But with increasing telescopic power, difficulties arose because different colors under given conditions are refracted by different amounts. To avoid these defects, telescope makers turned to the use of mirrors until John Dolland, about 1750, discovered how to correct the errors in refraction by using two pieces of glass having approximately compensating properties. Thus about a century before the invention of photography the requirements of astronomy led to the design and construction of achromatic lenses without which good photographs cannot be obtained in white light.

One of the properties of light which has come to play a fundamental rôle in recent physical theories is its velocity in vacant space. The fact that light traverses interplanetary spaces with a finite, though very great, velocity was discovered by Römer, in 1675, only sixty-six years after the invention of the telescope. In this day it is difficult to appreciate the rapidity of the development of observational astronomy which led to this discovery, or the profound effect it had upon scientific thought. It does not seriously detract from its importance that the value obtained by Römer for the velocity of light was about twenty per cent too large. The stimulating effect of the discovery that radiant energy is transmitted at a finite velocity is illustrated by the fact that Laplace attempted, but without success, to determine the velocity of gravitation.

Our familiarity with the numbers used in expressing the properties of radiant energy dulls us to the amazing realities they represent. The highest velocities with which scientists were familiar before the time of Römer were those of projectiles and of sound in the atmosphere, or of the order of a mile in five seconds. But light flashes through space at a speed equal to seven times the distance around the earth in a second. The lengths of its waves are of the order of a fifty thousandth of an inch. The number of its mysteriously transverse vibrations in a second is, in the case of yellow light, greater than the number of seconds in 18,000,000 years. These are the quantities that a world familiar only with such

things as the diameter of a hair and the speed of the flight of birds were suddenly asked to accept as realities.

For more than a century astronomers lamented the fact that there is dispersion of light because it impaired the excellence of their telescopes. Then they gradually came to realize with the development and application of the spectroscope that the composite character of light and its easy separability into its different wave lengths place within their hands an instrument of the most extraordinary value.

Let us sketch briefly the history of the development of the principles of spectrum analysis. In 1666 Newton passed sunlight through a prism and broke it up into its constituent colors, and he recombined them into white light by passing them through a similar prism in reversed position. For more than a century little progress was made in the analysis of light because all experimenters passed it through a small circular opening before it reached the prism, the images of which overlap and impair definition. Finally, in 1802, Wallaston introduced a narrow slit in place of a prism, the images of which are distinct lines. Immediately progress was rapid. By 1817 Fraunhofer had determined 324 characteristic absorption lines in the spectrum of the sun. All that remained was the formulation of the principles of spectrum analysis in order to interpret the meaning of the Fraunhofer lines and to place in the hands of astronomers a new means of investigation of the most extraordinary and unexpected importance. These principles were first approached by Ångstrom, in 1853, and by David Alter, of Freeport, Pennsylvania, in 1854; they were completed in their present form by Kirchhoff between 1859 and 1852.

And what of the results obtained by means of the spectroscope? By its use astronomers have determined the chemical constitution of the sun, its temperature, its period of rotation, the velocities of its violent eruptions, its magnetic condition, its distance from the earth, the density of its atmosphere, and have observed its prominences even when it is not eclipsed. For most scientific purposes the spectroscope has brought the sun down to the earth. It has become a physical laboratory in which the principles of spectrum analysis are verified in the flash spectrum at the time of an eclipse, in which tempera-

tures beyond these of terrestrial laboratories are always available, and in which theories of ionization can be verified.

As applied beyond the solar system, the spectroscope enables astronomers to determine the constitution of the stars, their temperatures, their velocities in the line of sight, often whether they are double and their periods of revolution, the masses and densities of certain of them, in some cases their periods of rotation, their distances, the existence and character of interstellar molecules, and the dimensions and the period of rotation of our galaxy.

Far beyond the borders of our galaxy are other galaxies, perhaps a hundred million of them within five hundred million light years, the greatest distance that can be reached at present. By means of the spectroscope astronomers prove directly in many cases that these galaxies are rotating and also measure their velocities of rotation. From what astronomers learn about these foreign galaxies they acquire a much better understanding of our own. There is, however, one phenomenon revealed by the spectroscope in connection with exterior galaxies that was wholly unexpected and has led to the most startling conclusions. I refer to the fact that their spectral lines are displaced toward the red end of the spectrum by amounts that are directly proportional to their distances. Whether the true explanation of these displacements of spectral lines is that they are due to velocities of recession which are greater the greater the distance of the galaxy, as seems reasonable from theory and from experience in our galaxy; or whether the effects are due to gradual diminutions of the quanta of energy in the passage of light through the enormous distances of intergalactic space without changing Planck's constant, it is perhaps too early to decide. In any case, these observed phenomena are raising questions of the most fundamental character. And the applications of the spectroscope to the sun and to the stars in our own galaxy have impelled scientists to speculate on the origin of radiant energy and the condition of matter having a density, in the dwarf stars, twenty thousand times as great as that of water.

It would be inexcusable to close these remarks without referring to Michelson's attempt to measure the velocity of the earth with respect to the ether and his failure to find the

expected result, for it led eventually to the theory of relativity and entirely new conceptions respecting the nature of the universe and of science. Moreover, it may be noted that nearly all the tests of the validity of the equations of relativity are astronomical in nature.

In summary, science originated in observations of the heavenly bodies, and its anthropomorphic character was successively weakened by the requirements of astronomical theories. The exterior universe has taught us much about our earth and its sciences, and much even about the workings of our own minds. The universal genius whose memory we honor today lived too early to know about most of the things of which I have spoken. But his daring spirit roamed thus widely through and beyond the science of his day, at one time reading the records of ancient life preserved in fossils in the rocks, at another drawing lightning from the clouds, at another finding delight in the wild flowers of the fields, at another turning his eyes and his mind to the stars. As a tribute to him I should like to paraphrase an epitaph which appears over the tomb of Newton in Westminster Abbey, where England has buried her noblest dead. In free translation it is: "Mortals, congratulate yourselves that so great a man has lived for the honor of the human race." Concerning Benjamin Franklin let us say: Americans, let us congratulate ourselves that so great a man has lived for the honor of our country.

VOLCANOES, GEYSERS AND HOT SPRINGS.*

BY

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Although volcanoes have been a subject of active inquiry for more than two hundred years and hot springs for perhaps half that time, there is an authoritative volume (Meunier, "Les Convulsions de l'Écorce terrestre") published as late as 1910, which warns us not to confuse volcanic phenomena with "pseudo-volcanic activity" (hot springs, mud volcanoes, etc.). More intensive studies of recent years, to which I invite your attention, seem to prove that all of these phenomena are but phases of the same terrestrial activity. The picture may be outlined in this way.

An outbreak of volcanism obviously can occur only in a region where the fluid magma approaches much closer to the surface than in other regions. To raise the question whether structural weakness of the overlying crust or the inherent boring power of magmatic solvents is mainly responsible for the opening is quite immaterial, since both factors doubtless enter into the determination of most volcanic vents. Also whether a lava outpouring takes place along a rift, as in Iceland, or through a well-established central cone, as at Vesuvius, is a question of local physical factors and their distribution. Local temperature, composition and fluidity of the magma and the magnitude of the accumulating pressure below, are factors calculated to seek out and determine the point of greatest weakness in the overlying crust. Given a very hot, highly fluid magma, such as the basalt of the Hawaiian volcanoes, and the eruption will usually consist of an explosive release of the accumulated gas pressure at the top of the lava column, followed by a more gradual escape of its volatile content and a quiet outpouring of the lava itself. In other cases where the viscosity of the magma is greater an

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outbreak will assume a quite different aspect, usually marked by dangerous explosive features. The chief emphasis for our consideration at the moment lies in the fact that the magma itself brings to the surface an immense source of energy which may be released under conditions determined by the amount of this energy, the chemical and physical constitution of the magma and the local resistance of the restraining crust. The fact that these magmatic sources of energy do approach the surface in this way is readily established wherever borings have been made in such regions, for the ground temperature downward rises very rapidly there as compared with other regions where no such approach occurs.

When the magma, highly charged with superheated steam and other gases, approaches close to the surface in this way it is obvious that partial release of its energy at the surface may also take place slowly by gas seepage or chemical attack upon the adjacent rocks as well as through an opening forced through a weak cover.

From this point our consideration leads us to inquire what the composition and physical character of the magma may be at these points of approach to the surface and what consequences may be expected at the surface as a result of this approach.

It is now nearly 200 years since Spallanzani observed that molten lava flowing out upon the surface did not burn on reaching the air and its liquid condition could not be due to burning sulphur or other fuel. He also appears to have been the first to suspect that the magma itself was charged with gaseous material which accounted for the explosive features and for the porosity of the lava after solidification. He also intimated that its fluidity may have been due to the presence of these volatile materials and that water may have been included among them. It was also frequently noticed by the earlier observers that showers of rain often follow immediately upon volcanic outbreaks, which can be attributed to the condensation of escaping steam.

It is not my purpose to follow through the ramifications and confusion of the controversy which has continued down to the present century regarding the character of this participation of water (i.e., steam) in volcanic outbreaks, a participa-

tion which appears always to have been but imperfectly understood and often flatly denied. Indeed as recently as 1911 Brun [1] published an elaborate volume containing analyses of collected volcanic products which purported to show that all volcanic emanations are anhydrous. This misunderstanding was dissipated the following year,[2] when volcanic gases were collected at Kilauea before they could be altered by contact with the air and considerable quantities of water condensed therefrom.

Out of this long controversy we may conclude that water (steam), and other gases which have since been identified, are essential ingredients of the magma below ground and participate actively in all the phenomena of volcanism. It remains for us to consider what effect this may have upon the observed surface behavior of volcanoes both at rest and in action.

In the first place it may happen that as the magma approaches the surface and the overlying load diminishes, some separation and concentration of these gaseous ingredients may occur at the top of the rising column of liquid magma. It must follow from this that the solvent action of these concentrated volatiles (water and acid gases) upon the overlying structure must be considerable at these high temperatures (above 1000° C.). Such increased mobility and solvent action must find and follow lines of structural weakness in the overlying crust (faults, joint cracks) and so facilitate the continued rise of the magmatic column and determine its direction. If the stored-up energy (pressure) below is very great rupture and a violent volcanic outbreak may be expected to develop eventually, which may be limited to the partial escape of the compressed and concentrated volatiles (e.g. superheated steam) at the top of a column, or may include or be followed by the still highly-charged liquid lava itself, as in the case of a bottle of soda water suddenly opened. Such an outbreak of magmatic energy is obviously a volcano.

But, suppose instead of this that the magmatic column approaching the surface encounters porous ground, and the

[1] "Recherches sur l'Exhalaison Volcanique," Geneva, 1911.

[2] A. L. Day and E. S. Sherpherd, "Water and Volcanic Activity," *Bull. Geol. Soc. Am.*, **24**, 573, 1913.

accumulated volatile materials in the upper layers of the column find opportunity for escape by seepage, what then is the result? The chemically active gaseous ingredients (chlorine, fluorine, sulphur) may gradually filter away and expend themselves in reactions in the passages of the overlying rock, enlarging these and perhaps altering the composition of the rock itself, while the superheated steam will continue on until it either escapes or condenses at or near the surface. Both of these activities result in a *gradual* release of the pressure at the top of the magmatic column, perhaps to the extent of preventing an explosive rupture of the restraining crust. Such cases exist and are revealed by the chemical alteration of the rocks, by the chemical content and temperature of the surface springs and by the rapidly increasing ground temperature immediately below the surface. Where rupture has occurred and a volcanic explosion takes place, there is of course abundant and readily available evidence of the activity of the volatile ingredients contained in the magma. When the eruption has subsided and the volcanic conduit is again wholly or partially closed, we must suppose that the release of pressure at the top of the column has stimulated the rise of these volatile materials from greater depths (and higher temperatures) within the liquid mass below and their escape under the ordinary action of gravity. These gases are near the surface now in a zone already perforated and may therefore readily find ways of escape by the slower processes of seepage and filtration until they encounter the cold ground water at the surface. Thereupon magmatic steam will condense, soluble gases (carbon dioxide, chlorine, etc.) will begin to enter solution in the surface water and the fixed gases (hydrogen, nitrogen) will continue on until they escape at the surface.

This ground water has its own circulation above ground, beginning with the rainfall which is distributed by surface runoff and by absorption into the surface layers and openings, and again below ground in seepage and through joint-cracks. Obviously the rainfall in the volcano region will find the ground temperature rapidly increasing as it seeps downward and its penetration will remain shallow and sharply limited wherever the boiling temperature is reached.

If we now suppose that in these regions superheated steam from the magma, more or less associated with the other gaseous products (carbon dioxide, chlorine, sulphur), to be approaching the surface from below and to encounter the surface-water circulation, certain results are immediately obvious. The superheated steam will condense, add its latent and superheat to the surface water, and mix with it, other gaseous ingredients will also enter the surface water to greater or less extent, according to their quantities and solubilities, and where these circulating surface waters reappear in springs above ground we may read therein the record of what has occurred. The springs will be hot instead of cold, they will contain carbon dioxide, hydrogen sulphide, chlorine, etc., in proportions appropriate to the solubility of these gases under the prevailing conditions. Or, if the non-condensable gases are in excess, we may find them bubbling through the surface springs themselves and escaping into the air where they may still be caught and analyzed.

Or again suppose these magmatic emanations happen to rise beneath steep hillslopes, where little or no storage of ground water is found. Then either one of two results will be in evidence: (1) very small springs highly concentrated with the acid ingredients coming from the magma, or (2) the free escape of the magmatic gases, including steam, into the air without previous condensation by ground water. In the first case there result strongly acid springs of small size and turbid, because of the acid attack upon the surrounding ground, in the second the free escape of magmatic gases into the air as roaring fumaroles, or steam jets.

Thus we have brought into a single category, now abundantly supported by experimental studies in the field, both the volcano and the hot spring. If the magmatic column rising to the surface carries with it a vast amount of compressed energy the crust may be violently ruptured and an explosive outbreak of both gaseous and liquid ingredients of the magma will inevitably result. When this violent phase has subsided and the major concentration of the more volatile portion of the rising magma near the surface has been discharged, it will almost certainly be followed, throughout the perforated region, by the continuing seepage of the volatile

ingredients which may be traced through the hot springs for hundreds or thousands of years thereafter, or may be interrupted from time to time by more violent phenomena in case the main conduit becomes closed or the accumulation of energy below ground is too rapid to be satisfied by seepage release.

Thus, for example, in the North Island of New Zealand we have a perforated zone running northeast and southwest more than half way across the Island. This hot-spring region is of considerable extent and includes at one end, and again near the middle, an active volcano. One of these volcanoes (White Island) rises from the sea beyond the coast line, is more or less continuously active, though only occasionally violent, and a number of hot springs and fumaroles are found there. Some of these are so highly charged with the acid emanations from the magma that the acid concentration in the springs sometimes reaches 10 per cent. It is the highest concentration of volatile magmatic elements which has hitherto been observed.

The other volcano (Tarawera) was violently active in 1886, the explosive activity tearing the mountain wide open from summit to base and opening a rift beyond the base into the hot-spring valley below which extended for a distance of nearly nine miles. Thus we have an intimate association in present time of active volcanism and hot-spring activity in the same area. It also fits in nicely with the above general outline that the hot-spring activity in the rift zone appears to be considerably diminished in volume and intensity since the explosive release of the high concentration of energy in 1886.

On the other hand we have in the Yellowstone Park a lava plateau of much more ancient date, in which the old centers of volcanic activity are long since closed, but which still shows abundant hot-spring activity throughout its extent of nearly 60 miles north and south. An intensive study of this region, undertaken during the last seven years, has provided a number of the supporting facts in the above analysis. Borings in two different localities revealed, in the region of most abundant surface water supply, a temperature of 180° C. at 406 ft. below the surface, in another region. of

somewhat less abundant surface water and therefore greater concentration of the products of volcanic emanation, the temperature reached 205° C. within 246 feet of the surface. Steam pressures at the bottom of these bore-holes amounted to 57 and 297 pounds per square inch respectively. Here also in the course of a chemical study of the hot springs it was found that in the basins, with abundant surface-water supply, the acid concentrations were found to be small, and on the hillsides, where water was much less abundant, the acid products of volcanic activity were much more highly concentrated.

In discussing the origin, behavior and chemical content of hot springs it is well to bear in mind that a hot spring differs from a cold spring not merely in the fact that it chanced to pass through hot rocks instead of cold ones in coming to the surface. If this were the case the hot springs might be expected to cool rapidly and so presently to become cold themselves for the rocks conduct heat but poorly. Take a notable example by way of illustration. The spectacular Old Faithful geyser in Yellowstone Park erupts quite regularly, about once an hour, an estimated 10,000 to 12,000 gallons of boiling water and so brings to the surface a nearly uniform quantity of boiling water annually. It is a matter of simple arithmetic to discover that the heat necessary to maintain this intermittent hot spring would require about two square miles of red-hot rock surface, of average heat conductivity, *renewed annually*, merely to heat the water regularly distributed by this geyser. Here it is pertinent to add that none of the hot water thrown out by Old Faithful returns down the conduit to aid in the next eruption; neither does the extreme cold of winter alter appreciably either the period of its eruptions or the amount of water which is thrown out hourly. We must also reckon with the fact that a dozen other large geysers and some hundreds of smaller hot springs share with Old Faithful the water supply of the Upper Geyser Basin in which it is located.

This leads us, I think, to an inevitable conclusion that the latent heat of more or less superheated steam coming from the magma below, seeping upward through hot ground and condensing upon contact with the circulating ground water

near the surface, is the only continuing source of energy which can possibly account for the uniform and continuous supply of heat to great groups of hot springs with a record of activity in their present location, as measured by the amount of sinter deposited upon their domes, of the order of magnitude of at least 10,000 years.

In elaboration of this hypothesis it is noteworthy that in regions of deep ground-water circulation this transfer of heat occurs at greater depth and so under higher pressure and temperature than upon hillsides, where the transfer must take place near the surface where the volume of water and the amount of heat available are both smaller. It is doubtless in consequence of this that neither large hot springs nor geysers are found there.

Further proof is available that hot springs in volcanic regions are heated by condensing steam out of the original magma itself. Surface waters, which circulate by flowing over the rocks or below ground through crevices or joint-cracks, always carry in solution traces of the rock materials through which they have passed. All springs therefore bear a definite record of the kind of rock through which the water has passed because of the soluble ingredients of the rock which are carried in solution. And so it happens that the hot springs of Yellowstone Park carry variable quantities of soluble minerals from the rocks which are readily identifiable by chemical analysis. But they also carry other chemical elements not found in the adjacent rocks such as sulphur, arsenic, boron, chlorine and fluorine, all of which are characteristic ingredients of volcanic emanations. We have therefore direct proof of the participation of the volcanic gases in hot spring activity.

The chemical evidence thus fits perfectly into the physical picture which we have built up of the behavior of magma on approaching close to the surface, first in its effects in altering the composition of the rocks into which it intrudes, second, in supplying ingredients to the circulating surface waters (ground waters), which can be traced to no other source, and finally to provide a continuous source of energy over long periods of time for hot springs, geysers and intermittent outbreaks of volcanism.

Up to this point little mention has been made of geysers which form an integral part of our title. The reason for this lies in the fact that the geysers form but a very special case of hot springs and occur only in particular hot-spring regions where certain very exceptional physical conditions are found. In order that we may have a geyser we must have not only a continuing supply of magmatic heat from below, represented by rising superheated steam as in the case of other hot springs, but also an abundant supply of circulating surface water in which the manner of circulation comes to have very special importance. Geysers can hardly occur without free circulation in underground channels of considerable size as opposed to the slow percolation of ordinary seepage. These channels are probably the outcome of earlier solvent action of the hot water accompanied as before by the more active chemical elements of the emanation. These channels must also have pockets of such character and distribution that water may enter and steam pressure may accumulate faster than it can escape by seepage. Such pockets or chambers imply a fairly deep-seated circulation compared with other surface waters in the volcano region, and somewhat greater age is indicated than in the case of the more widely distributed quiet hot springs. Both of these conclusions seem to follow from the fact that they must support pressures adequate to discharge considerable columns of water often to heights of several hundred feet. This seems to imply a period of existence sufficient to provide chambers of considerable size and to seal them more or less effectively through deposition of mineral matter from the circulating water itself.

There are but three major geyser regions known in the world today. The largest is in the Yellowstone Park, which has already been mentioned, next to it in the number of its geysers is the North Island of New Zealand, and finally the well-known geyser region of Iceland, which, by the way, contains relatively few geysers but hot springs in thousands and several intermittently active volcanoes. The geysers of Iceland were the first to become widely known and the word "geyser" or "geysir" comes from that country.

The Yellowstone Park in which the geyser phase appears to have reached its highest development is farthest removed in

time from any active volcanism. There are glacial boulders from the last ice age scattered over some of the hot-spring formations which may indicate an age of upwards of 50,000 years. In both Iceland and New Zealand, where the number of geysers is much smaller, active volcanism is still closely associated with all of the hot-spring activity. This fact may be relevant to the conclusion that time is also necessary for the development of the peculiar local formations in which geysers are built up.

The mechanism of a geyser is not fully understood even today, although Bunsen, as early as 1847, offered a theory of the mechanism of the Great Geyser in Iceland which has (somewhat arbitrarily) received general application and acceptance for all geysers since that time. It ought not to be forgotten that Bunsen did not offer it as a general theory of geysers, nor was the Yellowstone Park discovered at the time when Bunsen wrote. Perhaps it is not strange that it does not fit the Yellowstone geysers. Being developed from observations on a single geyser Bunsen's theory appears today in the light of available modern data to be precisely what Bunsen intended it to be, namely, a mechanism to account for the Great Geyser only. Its application to the other geysers of the world is not quite justifiable without appropriate adaptation. For example, the Great Geyser of Iceland in Bunsen's time erupted periodically through a large shallow bowl at the surface. With the subsidence of the eruptive feature the accumulation of cooled water in the surface bowl retreated down the tube and disappeared, presumably aiding to condense the compressed steam below and so to end the eruption. In the Yellowstone Park most of the geysers are without this catch basin at the surface and therefore do not return this cooled water to the zone of high steam pressure. According to Bunsen's mechanism, therefore, such geyser eruptions would not stop but would go on in continuous steam jets without intermittent features. It is likewise pertinent to call attention to the fact that Bunsen's theory of the mechanism of the Great Geyser provides for a strictly periodic system, i.e., for eruptions at substantially equal time intervals. With the exception of Old Faithful, to which reference has already been made, few of the Yellowstone geysers exhibit even

approximate uniformity in the time interval between eruptions. The Giant, for example, plays at intervals of from two to eighteen days.

Perhaps this is not the appropriate time or place for the discussion of these details, but it is surely sufficiently plain from such illustrations that the mechanism of a geyser, whether periodic or merely intermittent, is somewhat more intricate than the simple one suggested by Bunsen nearly a century ago.

It is a matter of some interest in passing that many geysers have not proved to be permanent features of hot-spring activity, even during the years of this present century when they have been under closer observation. The Excelsior, which was probably the greatest geyser to appear in the Yellowstone Park within the period of historic record, apparently destroyed its own "plumbing" by the violence of its eruptions, for rocks were frequently thrown out during eruptions and the violent intermittent explosions of the geyser, which were characteristic of the closing years of the last century, have since given way to a continuous flow of hot water. The Imperial Geyser, also in the Yellowstone Park, had a similar, though much shorter, history (about 18 months). Waimangu Geyser, in New Zealand, which probably threw water to a greater height (over 1000 feet) than any other geyser known to us, appears to have ended a three-year period of geyser activity in 1905 and today not even a hot spring marks its former location. These are exceptional cases and hardly prove anything more than that too great a concentration of power sometimes leads to the rupture of the sealed chambers and tubes which are necessary to such regulated discharge. As has been stated above, the deposition of silica sinter (geyserite) about some of the geyser openings indicates continuous activity in the same spot for upwards of 10,000 years at the slow rate at which such deposition occurs. Castle, Grotto, White Dome and Old Faithful geysers in Yellowstone Park are illustrations of this.

It is also true that new geysers sometimes appear in these geyser regions and others long dormant return to activity after years of complete subsidence. The New Zealand field

contains several notable examples of these long pauses in geyser history (Waikite, Pohutu).

Such a presentation of the volcano-hot-spring problem can provide but the briefest sort of summary of the long campaign of field and laboratory studies extending over more than twenty-five years in time and into several different countries, but it is hoped that the evidence here brought together is sufficiently pertinent and convincing to leave no reasonable doubt that volcanoes and hot springs have a common source of energy, namely, the magma approaching the surface and cooling there, and that the most active agents both in volcanic outbreaks and in hot springs are the more volatile components of the magma which seek to escape as it approaches the surface, and whose subsequent behavior is determined by their composition, by the total energy available, the temperature and the local conditions encountered.

L'HOSPITALISATION DES MALADIES CONTAGIEUSES.*

PAR

LOUIS MARTIN, M.D.,

Directeur, l'Institut Pasteur, Paris.

Mesdames,
Messieurs,

Quand j'ai reçu une invitation pour venir à Philadelphie assister à l'inauguration du Mémorial en l'honneur de Benjamin FRANKLIN, je me suis demandé s'il était sage de venir aux Etats-Unis alors que mon âge me conseillait d'éviter les longues traversées et que les devoirs de ma charge pouvaient me dissuader d'entreprendre ce voyage.

Toutefois, avant de répondre à votre si honorable invitation, j'ai voulu me documenter sur Benjamin FRANKLIN et j'ai appris qu'il était âgé de 71 ans quand il est venu en France, où il était resté huit ans, loins de son pays, pour obtenir et assurer l'indépendance des Etats Unis.

Désireux de suivre l'exemple donné par Benjamin FRANKLIN, j'ai accepté de venir aux Etats-Unis fêter un grand Homme d'Etat, un grand philosophe, un grand Savant, un grand Ami de la France.

Je suis ici pour participer à l'hommage rendu à Benjamin FRANKLIN au nom des disciples du grand Maître PASTEUR et aussi au nom de l'Académie des Sciences dont FRANKLIN fut membre associé de 1772–1790.

. . .

J'ai choisi comme sujet de mon allocution une étude sur l'hospitalisation des maladies contagieuses. J'ai vu que Benjamin FRANKLIN avait fondé un hôpital à Philadelphie et qu'il s'était tellement intéressé à cette fondation que dans son testament il laissait une partie de sa fortune à l'hôpital de Philadelphie.

* Presented Friday afternoon, May 20, 1938.

Je n'ai pas voulu vous parler des hôpitaux généraux car vous avez en Amérique de très beaux centres hospitaliers; mais j'ai pensé vous intéresser en vous donnant les résultats d'une observation de 38 années, car il y a déjà 38 ans que l'hôpital de l'Institut Pasteur a été fondé et qu'il fonctionne.

C'est au cours de nos études sur le traitement de la diphtérie par la sérothérapie que nous avons été amené à nous occuper de l'hospitalisation des maladies contagieuses.

Avec MM. Roux et Chaillou nous traitions, en 1894, les diphtériques dans un pavillon où tous les malades suspects de diphtérie étaient hospitalisés dans de grandes salles; nombreuses étaient les erreurs de diagnostic; plus fréquentes, et surtout plus funestes, les complications ou les infections surajoutées. Dans les cas de croup opéré, les malades mouraient de broncho-pneumonie; la rougeole ou la scarlatine guettaient les convalescents et souvent, malgré la sérothérapie, les enfants succombaient.

Il n'y avait à cela qu'un remède: l'isolement individuel; c'est ce que nous avons tenté à l'hôpital Pasteur.

Le programme a été présenté en quelques lignes par notre Maître, M. ROUX.

"Tout entrant est suspect et doit être isolé dans des sortes de boxes, clos, faciles à désinfecter et disposés de telle sorte que le personnel ne puisse transporter les infections de malade à malade."

Pour répondre à ce programme, il était essentiel de placer le plus grand nombre des malades dans des chambres à un lit; l'ensemble de ces chambres constitue le service d'isolement.

Quand la période aigüe est terminée, nous réunissons les malades dans les chambres à trois lits; le groupement de ces chambres constitue le service des convalescents.

(*a*) *Service d'isolement.* Dans chaque pavillon le rez-de-chaussée et le premier étage sont identiques.

Le service des isolés est composé de 12 box entièrement autonomes et séparés des autres services par deux couloirs d'isolement. Ces 12 box ont deux portes; l'une donnant sur un couloir intérieur, l'autre sur un balcon extérieur.

Médecins et infirmières peuvent se rendre auprès du malade par l'intérieur, à condition de ne négliger aucune règle de l'asepsie médicale. Mais, si l'on veut isoler plus

particulièrement un malade, on peut se servir du balcon extérieur; cette seconde pratique s'impose rarement.

Installation d'un box. Dans chaque box il existe une arrivée d'eau froide et d'eau chaude (80°), un évier, une bonde de vidage pour recevoir les eaux d'écoulement.

Le sol est absolument imperméable.

Les murs sont lavables, les soubassements, en grès cérame ou en lave émaillée, peuvent être désinfectés par des antiseptiques liquides.

Dans chaque cellule, il existe une bouche d'air chaud et un orifice de ventilation. Une prise d'électricité permet soit la stérilisation par l'ébullition dans le box même, soit la production de vapeur d'eau afin d'obtenir une atmosphère saturée d'humidité. L'éclairage est assuré par une lampe électrique et par une prise de courant.

L'installation du box permet de donner un grand bain près du lit du malade.

Après le départ de chaque hospitalisé, la désinfection est facile; on lave à l'eau de Javel à 1/50 toutes les parties basses de la pière et avec un jet d'eau les parties hautes; à la rigueur, il est possible de désinfecter à l'aldéhyde formique. Dans la pratique les grands lavages suffisent.

Deux des parois du box sont vitrées, ce qui facilite la surveillance et rend l'isolement moins pénible. Le malade reste ainsi en contact avec le monde extérieur et en éprouve une grande satisfaction.

Le malade mis en box est à l'abri de tout apport de germe étranger. Aucun germe nocif ne pénètre dans sa chambre ni n'en sort.

Le malade est protégé contre les germes du dehors, car il ne reçoit pas de visites, à part de très rares exceptions. Personne ne doit pénétrer dans sa chambre, sauf les infirmières et les médecins, qui alors observent toutes les règles de l'asepsie. Les parents peuvent voir leur malade et même causer avec lui à travers la porte vitrée de la cellule qui donne sur le balcon extérieur.

Toute la vaisselle ayant servi au malade isolé est désinfectée à l'office des pavillons par ébullition dans l'eau carbonatée sodique.

Les chambres sont entourées par deux couloirs qui donnent accès sur le balcon extérieur et permettent une ventilation rapide et énergique du pourtour des cellules. En été, grace à cette installation, on établit autour des box un courant d'air qui maintient une grande fraîcheur dans l'hôpital sans incommoder les malades.

(*b*) *Service des convalescents.* Le service des convalescents comporte quatre chambres à trois lits. Tout d'abord à l'hôpital Pasteur, nous avions adopté une installation conforme aux pratiques hospitalières alors en usage, et le service des convalescents comprenait une seule salle de douze lits, mais il nous fut impossible de réunir 12 malades convalescents relevant de la même maladie. Par la suite, nous avons obtenu de très bons résultats en divisant cette salle de douze lits en quatre chambres de trois lits; ce qui a permis de former quatre groupes de trois personnes pouvant avoir quatre maladies différentes. Ces chambres sont utilisées pour les convalescents de scarlatine ou pour les porteurs de germes diphtériques.

Les chambres de convalescents offrent les mêmes commodités que les box: elles sont, comme eux, lavables et désinfectables, mais ne possèdent pas de balcon extérieur et c'est un oubli à réparer dans l'avenir.

FONCTIONNEMENT DE L'HOPITAL.

L'hôpital était destinë exclusivement à des contagieux et, primitivement, à des diphtériques. Mais, après peu de temps, il fallut reconnaître l'impossibilité d'avoir constamment 60 malades atteints de la même maladie.

Nous pensâmes alors diviser l'hôpital en compartiments, chacunne recevant que des personnes atteintes de la même maladie. Ce système ne put fonctionner: lorsqu'il y avait des places dans le service diphtérique, un varioleux se présentait. Force fut donc, pour utiliser plus complètement le pavillon, de supprimer tout classement *à priori*. Dès lors, la plus grande prudence devint la règle: on multiplia les précautions pour éviter toute contagion, mais on reçut dans un même pavillon toutes les maladies contagieuses et aussi, nous le verrons plus loin, des malades non contagieux.

Le tableau suivant indique bien comment nous avons fonctionné.

STATISTIQUE DES TRENTE-HUIT PREMIÈRES ANNÉES.

	Cas	Decès	%
Cancer	2,375	90	3.83
Coqueluche	415	37	8.71
Diphtérie	3,101	201	6.64
Angines non diphtériques et stomatites	3,410	16	0.46
Encéphalite léthargique	70	10	14.29
Entérite	416	77	18.59
Erysipèle	3,364	177	5.37
Fièvre typhoïde	1,522	151	10.20
Grippe	1,299	56	4.45
Lèpre	56	2	3.57
Maladies organiques diverses	5,684	491	8.63
Maladies exotiques	957	23	2.40
Mères et enfants non malades	2,389	—	—
Méningite microbienne non tuberculeuse	103	74	40.48
Oreillons	860	—	—
Rage déclarée	52	52	100
Rougeole	3,285	86	2.50
Scarlatine	5,697	112	2.01
Syphilis	505	14	2.78
Tétanos	113	54	47.27
Traitement antirabique	246	—	—
Tuberculose	617	306	50
Vaccination antiamarile	45	—	—
Varicelle	460	3	0.66
Variole	550	99	18
	37,671	2,131	5.65

Comme vous me l'avez demandé, je vais maintenant vous exposer l'activité de nos services en étudiant les principales maladies microbiennes.

Rage. C'est après la découverte du traitement antirabique qu'une souscription internationale a permis la fondation et la construction de l'INSTITUT PASTEUR.

Il y a de cela cinquante années et au mois d'Octobre nous fêterons ce cinquantième anniversaire.

Depuis 1888, le service antirabique a toujours fonctionné régulièrement, il a reçu 53,000 personnes.

D'années en années les résultats obtenus se sont constamment améliorés et si nous prenons les chiffres des treize dernières années nous voyons que sur 7,285 personnes qui ont été traitées à l'Institut Pasteur de Paris, *il n'y a pas eu un seul décès.*

Il n'est pas possible de trouver une meilleure preuve de l'efficacité du traitement antirabique.

Diphtérie. Je vous rappelle que l'hôpital Pasteur était primitivement destiné à l'hospitalisation des diphtériques. Le Dr. ROUX, lors de la communication de Budapest en 1894, avait démontré l'efficacité de la sérothérapie antidiphtérique et le Monde entier avait aussitôt traité par la sérothérapie cette terrible maladie.

A l'hôpital Pasteur, nous avons hospitalisé 3,101 diphtérie avec 201 décès ce qui représente une mortalité de 6.64%.

Après 1923, pour combattre et prévenir la maladie, nous avons obtenu d'excellents résultats; car nous possédons un procédé très efficace de vaccination avec l'anatoxine de Ramon. Cette anatoxine dérive de la toxine diphtérique découverte par MM. Roux et Yersin. Ce poison mélangé à du formol et porté à l'étuve perd sa toxicité et devient vaccin.

Les premiers travaux sur cette importante question remontent à 1923 et les premiers vaccinés l'ont été à l'hôpital Pasteur.

Depuis, chaque année, on note à Paris une diminution de la morbidité et de la mortalité.

La diphtérie est la maladie qui a le plus profité des méthodes pastoriennes.

Voici des chiffres qui indiqueront mieux qu'un long discours les résultats obtenus: dans les quatre années qui ont précédé la communication de Budapest, on avait noté à Paris une moyenne annuelle de 1,430 décès, l'an dernier pour toute la ville de Paris il y a eu moins de cent décès, exactement 87.

Depuis deux ans nous avons vacciné l'armée française en associant divers vaccins soit l'anatoxine diphtérique, l'anatoxine tétanique et le mélange bacilles typhiques et paratyphiques.

Nous pratiquons trois vaccinations espacées de quinze jours.

Les résultats ont été excellents. Ces vaccinations associées sont bien supportées et se sont montrées très efficaces.

Variole. L'étude de cette maladie a tout particulièrement intéressé FRANKLIN car il a étudié sa prophylaxie par l'inoculation; d'abord hésitant presque hostile il l'accepta plus tard après avoir constaté ses bons effets de l'inoculation en Angleterre. Qu'il eut été heureux s'il avait pu constater les résultats de la vaccination jennerienne.

Nous avons hospitalisé 550 varioleux et la mortalité a été de 18%.

Si nous trouvons en 1900 un si grand nombre de varioles c'est qu'à cette époque la vaccination n'était pas encore obligatoire. En tout cas l'épidémie de 1900 a été la dernière qui fut observée à Paris.

Rougeole. Nous avons hospitalisé 3,285 rougeoleux avec 86 décès soit une mortalité de 2.50%. Ces résultats sont ceux qu'on obtient quand les malades sont soignés dans leur famille. C'est pour la rougeole que l'isolement individuel se montre le plus efficace.

Scarlatine. En France la scarlatine est relativement bénigne. 5,697 malades ont été soignés et on a noté 112 décès soit une mortalité de 2.01%.

Erysipèle. 3,364 malades ont été soignés, la mortalité a été de 177, soit 5.37%. Les derniers travaux sur la sulfamide, qui a une action spécifique contre les streptocoques, permettent d'espérer une diminution de la mortalité. Je rappelle que des malades atteints de méningite à streptocoque ont guéri quand ils ont été traité avec la sulfamide.

FRANKLIN avait étudié la grippe, le rhume; il espérait connaître le mécanisme de la contagion. Il faut avouer que nos recherches n'ont pas fait progresser cette étude; nous avons hospitalisé 1,299 malades avec 56 décès soit une moyenne de 4.45%. De nombreux chercheurs sont actuellement sur la question, l'agent causal a été étudié notamment en Amérique; on a trouvé des animaux sensibles, ce qui laisse espérer de beaux travaux, de belles découvertes.

Il est toujours intéressant d'avoir des renseignements sur les maladies qui frappent les humains dans tous les pays, la fièvre typhoïde est de ce nombre; en donnant de l'eau potable, privée de germes nocifs, au populations, on diminue considérablement les cas; mais pour les malades la mortalité reste encore élevée. Nous avons reçu 1,522 malades et enregistré 151 décès soit 10.20%.

Dans l'armée la vaccination antityphique a fait disparaître la fièvre typhoïde, ce qui n'est pas pour la population civile qui redoute la vaccination.

L'hôpital Pasteur reçoit des contagieux, mais comme je l'ai dit on peut admettre des malades non contagieux ce qui a permis d'étudier diverses maladies. Nous signalerons la syphilis, la maladie du sommeil chez les Blancs, la spirochétose ictérohémorragique, le tétanos.

Pour la syphilis nous avons été des premiers à pratiquer l'injection intraveineuse de 606, qui s'est montrée très efficace. 505 malades ont été hospitalisés, il y a eu 14 décès.

Maladies exotiques. Nous avons étudié 957 maladies exotiques et plus particulièrement la maladie du sommeil.

Nous avons soigné 811 coloniaux, il y avait des paludéens, des malades atteints de sprue, de dysenterie. Nous avons surtout étudié et suivi des blancs atteints de la maladie du sommeil.

Maladie du sommeil. Pendant longtemps, on a pensé que la maladie du sommeil n'existait pas chez les blancs. Nous avons reçu notre premier malade en 1904; depuis, nous avons examiné plus de 80 Européens venus principalement du Congo.

Chez les blancs, la trypanosomiase évolue le plus souvent sans provoquer la somnolence qui caractérise la maladie chez le noir; c'est ce qui explique que, dans bien des cas, les atteintes du mal ont dû passer inaperçues ou ont été diagnostiquées tardivement.

De nos observations, nous avons déduit des faits intéressants sur le début, les symptômes, les formes, le diagnostic, l'évolution, le pronostic de la maladie.

Nous avons plus particulièrement étudié le traitement.

Après des tâtonnements et de nombreux essais, nous avons conseillé de traiter les malades blancs en associant l'atoxyl à l'émétique.

Nous avons indiqué les doses à employer et précisé comment on pouvait expliquer et éviter les échecs du traitement.

Nous pouvons résumer ainsi les résultats obtenus: si nous divisons en quatre séries les 80 premiers malades observés:

pour les 20 premiers, deux malades ont survécu,

pour les 20 du deuxième groupe, il y a eu une guérison sur deux malades;

pour les 20 du troisième groupe, la mortalité a été inférieure à un tiers et pour les suivants nos résultats se sont encore améliorés.

Spirochétose ictéro-hémorragique. Après Inada et Ido et grâce à l'obligeance du regretté Adrien STOKES nous avons pu traiter plusieurs malades et fixer la période d'incubation entre six et huit jours. Nous avons aussi préconisé la recherche du pouvoir agglutinant pour établir un diagnostic rétrospectif.

Signalons enfin que sur 113 tétaniques, nous avons eu une mortalité de 47.27% soit 54 décès.

. . .

Jusqu'ici je vous ai indiqué tout ce qui milite en faveur de l'hospitalisation cellulaire mais je ne dois pas vous laisser ignorer les cas de contagions intérieures et je désire aussi vous exposer les charges budgétaires.

Etude économique. Voyons d'abord la partie économique, le premier établissement d'un hôpital à isolement individuel coute plus cher que l'hospitalisation en grandes salles d'environ un tiers. Mais dans les pavillons spécialisés très souvent les lits ne sont pas occupés et le personnel parfois trop nombreux, d'autres fois insuffisant. Au pavillon Pasteur les lits sont tous occupés, en tout cas rarement vides et les dépenses d'entretien sont de ce fait très diminuées.

Contagions intérieures. Pour être complet, je dois vous indiquer ce que nous avons observé comme contagions intérieures. Nous nous sommes assez bien défendus puisque les contagions intérieures ont été de moins de deux pour mille; sur 37,671 malades que nous avons hospitalisé, les contagions que nous avons noté le plus fréquemment ont été:

7 varioles,
32 rougeoles,
4 érysipèles,
2 diphtéries,
10 scarlatines,
8 varicelles.

D'après ces chiffres, c'est la rougeole qui est la maladie la plus contagieuse. C'est au début du fonctionnement de l'hôpital que les contagions ont été les plus nombreuses.

Le personnel avait besoin de se perfectionner et comme les contagions résultaient presque toujours d'une faute commise

par le personnel, ces fautes étant évitables, les contagions ont diminué notablement dans les années suivantes.

Ce que je viens de dire prouve que pour soigner les malades il faut des infirmières instruites théoriquement et pratiquement, il faut au moins trois années pour former des infirmières destinées aux services de contagieux. Ce que nous avons obtenu, ne l'aurait pas été sans leur zèle et leur dévouement.

. . .

Après cet exposé qui se déduit de 36 années d'observation je tiens à dire que c'est une grande joie pour moi de pouvoir associer dans ces fêtes les noms de Benjamin FRANKLIN et de PASTEUR.

Tous deux ont eu pour idéal de soulager notre pauvre humanité.

Leurs travaux sont connus de tous et ils sont pour le grand public l'un celui qui a dompté la foudre, l'autre celui qui nous a délivré des maladies qui décimaient les peuples.

Si la France a la grande gloire d'être la patrie de PASTEUR, ne puis-je pas dire que Benjamin FRANKLIN est aussi des nôtres, il ne faut pas oublier que pendant huit années il a séjourné parmi nous et qu'il a fréquenté régulièrement l'Académie des Sciences. Sur la proposition de Mirabeau, l'Assemblée Nationale lui a voté un hommage qui jusqu'ici était réservé aux Princes et aux Rois.

Je termine cette allocution en citant le passage essentiel de la proposition de Mirabeau:

"Le Congrès a ordonné dans les quatorze états de la confédération un deuil de deux mois pour la mort de FRANKLIN et l'Amérique acquitte en ce moment ce tribut de vénération pour l'un des pères de sa constitution.

"La France éclairée et libre doit un témoignage de souvenir et de regret à l'un des plus grands des Hommes qui aient jamais servi la philosophie et la liberté.

"Je propose qu'il soit décrété que l'Assemblée Nationale portera pendant trois jours le deuil de Benjamin FRANKLIN.

"L'Assemblée adopte par acclamation."

THE HOSPITALIZATION OF CONTAGIOUS DISEASES.*

BY

LOUIS MARTIN, M.D.,

Director, The Pasteur Institute, Paris.

* * * * * * * *

Ladies and Gentlemen:

When I received an invitation to come to Philadelphia to take part in the inauguration of a memorial in honor of Benjamin Franklin, I asked myself whether it were wise to come to the United States when my age counseled me to avoid long voyages and when the duties of my position might well have dissuaded me from undertaking the trip.

However, before replying to your very gracious invitation, I sought to inform myself concerning Benjamin Franklin, and I learned that he was 71 years old when he came to France, where he remained eight years, far from his country, in order to obtain and assure the independence of the United States.

Being desirous to emulate the example given by Benjamin Franklin, I decided to come to the United States to honor a great statesman, great philosopher, great scientist, and a great friend of France.

I am here to participate in the homage to be rendered to Benjamin Franklin on behalf of the followers of the great master, Pasteur, and, also, on behalf of the Academy of Sciences, of which Franklin was an associate member from 1772 to 1790.

* * * * * *

I have chosen as the subject of my assignment a study of the hospitalization of contagious diseases. I observed that Benjamin Franklin had founded a hospital in Philadelphia and that he was so greatly interested in this foundation that in his will he left a part of his fortune to the Pennsylvania Hospital.

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* Translated by John Frazer, Ph.D.

I shall not speak about general hospitals for you have in America very fine hospital centers; but I thought it might interest you to give you the results of observations covering 38 years, for the hospital of the Pasteur Institute was founded 38 years ago.

It is in connection with our studies on the treatment of diphtheria by serotherapy that we have come to concern ourselves with the hospitalization of contagious diseases.

In 1894, with Drs. Roux and Chaillou, we treated diphtheritic patients in a ward where all those suspected of diphtheria were placed; many were the mistakes of diagnosis; frequent and often fatal were the complications resulting. For example in the case of curable diphtheria, the patients died of bronchopneumonia; measles and scarlet fever patients watched the convalescents, and often, in spite of serotherapy, children succumbed.

For this there was but one remedy: individual isolation; it is this that we have tried to employ at the Pasteur Hospital.

The program was drafted briefly by our master, Dr. Roux.

"All patients admitted are to be considered as under suspicion and should be isolated in independent compartments, sealed, easy to disinfect, and arranged in such manner that the personnel would not carry infections from patient to patient."

To achieve this program, it was essential to place most of the patients in rooms with one bed; the group of such rooms to constitute isolation units.

When the acute period is over, we reunite the patients in one room of three beds; the arrangement of these rooms constituting the convalescent service.

(*a*) *Isolation Service.* In each pavilion the ground floor and the second story are identical.

The isolation service consists of twelve compartments entirely autonomous and separated from the other departments by two isolation corridors. These twelve compartments have two doors each; one leading to an interior hall and the other to an exterior balcony.

Physicians and trained nurses may reach the patients from the inner corridor, strictly observing every rule pertaining to medical asepsis. But if one wishes to isolate a patient more

particularly, one can enter from the exterior or balcony door; this latter practice, however, being rare.

Arrangement of a Compartment. Each compartment is equipped with hot (80°) and cold water, a sink, and a drain pipe.

The walls are washable; the surbases, made of ceramic stone or of concrete, can be disinfected by antiseptic solutions.

In each compartment there is a hot air register and a ventilation shaft. An electrical outlet permits either sterilization by boiling in the compartment itself, or the production of water vapor in order to obtain a saturated atmosphere. Light is provided by an electric lamp. There is, also, an additional electrical outlet.

The arrangement of the compartment permits bathing a patient at the bedside.

After the discharge of each patient, disinfection is simple; washing the lower parts with 2 per cent. Javel water and the upper with a stream of water from a hose. If necessary, it is possible to disinfect with formaldehyde. In practice, ordinary washing with Javel water is sufficient.

Two sides of the compartment are provided with windows, which facilitates observation and renders isolation less irksome. The patient, consequently, is able to keep in touch with the exterior world and derives from it much satisfaction.

The patient thus installed in such a compartment is completely protected from foreign germs. No germ can penetrate into the chamber, nor emerge.

The patient is protected from outside germs, for he has, except on rare occasions, no visitors. Nobody is permitted to enter the chamber except the nurses and the physicians, who then observe all the rules of asepsis. Relatives may see the patient and even speak with him through the glass door of the compartment facing the exterior balcony.

All utensils used by the isolated patient are disinfected in a central room by boiling in a sodium carbonate solution.

The rooms are surrounded by two corridors which give access to the exterior balcony and permit of rapid and thorough ventilation of the compartments. In summer, due to this arrangement, there are set up around the compartments air

currents which maintain a decided coolness in the hospital without inconveniencing the patients.

(*b*) *Convalescent Department.* The convalescent department consists of four three-bed rooms. First of all, at the Pasteur Hospital, we had adopted a system conforming to the then existing hospital practice, and the convalescent department consisted of a single ward of twelve beds; but it was not always possible for us to assemble twelve patients convalescing from the same disease. Consequently, we have obtained very good results in dividing this ward of twelve beds into four rooms of three beds each, thus accomodating four groups of three persons each and providing for different diseases. These rooms are used for convalescents from scarlet fever or for carriers of diphtheria bacilli.

The convalescent rooms have the same facilities as the compartments; they are, like them, capable of disinfection, but have no exterior balcony—an oversight which is to be rectified in the future.

THE OPERATION OF THE HOSPITAL.

The hospital was originally destined exclusively for contagious diseases, and at first for diphtheritics. But, after a short time, we were obliged to recognize the impossibility of constantly having sixty patients with the same disease.

We thought then of dividing the hospital into sections, each receiving only patients having the same malady. This system did not succeed, for when there was room in the diphtheria department, a smallpox case would appear. It was necessary, therefore, to employ the ward more extensively and minimize all preliminary classification. From that time on, greater prudence became the rule: precautions were multiplied in order to avoid all contagion, but all the contagious diseases were received in the same department and, also, as we shall see further on, patients having no contagious diseases.

The following table indicates how we have succeeded.

As requested by you, I shall now describe the procedure of our departments in studying the principal diseases due to microörganisms.

STATISTICS OF THE FIRST THIRTY-EIGHT YEARS.

	Cases	Deaths	Percentage
Cancer	2,375	90	3.83
Whooping-cough	415	37	8.71
Diphtheria	3,101	201	6.64
Angina—not diphtheritic or stomatic	3,410	16	0.46
Encephalitis (lethargic)	70	10	14.29
Enteritis	416	77	18.59
Erysipelas	3,364	177	5.37
Typhoid fever	1,522	151	10.20
Grippe	1,299	56	4.45
Leprosy	56	2	3.57
Various organic diseases	5,684	491	8.63
Exotic diseases	957	23	2.40
Mothers and children—not patients	2,389	—	—
Non-tuberculous meningitis	103	74	40.48
Mumps	860	—	—
Rabies	52	52	100
Measles	3,285	86	2.50
Scarlet fever	5,697	112	2.01
Syphilis	505	14	2.78
Tetanus	113	54	47.27
Anti-rabic treatment	246	—	—
Tuberculosis	617	306	50
Vaccination antiamarile	45	—	—
Chicken-pox	460	3	0.66
Smallpox	550	99	18

Rabies. It was after the discovery of the anti-rabic treatment that an international subscription led to the foundation and construction of the Pasteur Institute.

It has been fifty years since then, and next October we shall celebrate the fiftieth anniversary.

Since 1888 the anti-rabies department has functioned without intermission and has received 53,000 persons.

From year to year the results obtained have constantly improved and, if we take the figures for the last thirteen years, we see that of 7,285 persons treated at the Pasteur Institute in Paris, *there has not been a single death.*

It is impossible to find a better proof of the efficacy of the anti-rabies treatment.

Diphtheria. I remind you that the Pasteur Hospital was originally organized for the hospitalization of diphtheria patients. Dr. Roux, after the paper in Budapest in 1894, had proven the efficacy of anti-diphtheritic serotherapy and the whole world immediately began to treat this terrible disease by means of serotherapy.

At the Pasteur Hospital we have admitted 3,101 diphtheritics with 201 deaths, representing a mortality of 6.64 per cent.

After 1923, we obtained excellent results in combatting and preventing this disease for we possess a very effective process of vaccination with the Ramon antitoxin. This antitoxin is derived from the diphtheritic toxin discovered by Drs. Roux and Yersin. This poison mixed with formaldehyde and desiccated, loses its toxicity and becomes a vaccine.

The first research on this important question goes back to 1923 and the first persons to be vaccinated were vaccinated at the Pasteur Hospital.

Each year since then, there has been noted in Paris a diminution both of morbidity and of mortality.

The treatment of diphtheria has profited most of all by the methods of Pasteur.

Here are figures which will show better than a long discourse the results obtained: in the four years that preceded the paper at Budapest there had been noted in Paris an average annually of 1,430 deaths; last year for the entire city of Paris there were less than one hundred deaths, to be exact—87.

During the last two years we have vaccinated the French army by combining different vaccines, either diphtheritic antitoxin, tetanus anti-toxin and a mixture of typhoid and paratyphoid bacilli.

We administer three vaccines fifteen days apart.

The results have been excellent. These combined vaccinations have caused little reaction and have shown themselves to be very effective.

Smallpox. The study of this disease particularly interested Franklin, for he studied its prophylaxis by inoculation; first hesitating and almost hostile to the theory, he later accepted it after having observed the good results of inoculation in England. How happy he would have been if he had been able to observe the results of vaccination according to the method of Jenner!

We have had 550 smallpox patients and the mortality has been 18 per cent.

If we find in 1900 so great a number of smallpox cases, it is because at that time vaccination was not yet compulsory. The epidemic of 1900 was the last observed in Paris.

Measles. We have had 3,285 measles cases with 86 deaths or a mortality of 2.50 per cent. These are the results obtained when the patients were treated at home. For measles, individual isolation has been shown to be far more efficacious.

Scarlet Fever. In France scarlet fever is of a relatively benign type. 5,697 patients have been cared for with 112 deaths, that is a mortality of 2.01 per cent.

Erysipelas. 3,364 patients have been cared for, with a mortality of 177 or 5.37 per cent. The latest researches on sulfamide, which has a specific action against streptococci, allows us to hope for a diminution in mortality. I note also that streptococcic meningitis has been cured when treated with sulfamide.

Franklin had studied grippe and colds; he hoped to understand the mechanism of contagion. We must confess that our researches have not progressed very far in this study. We have had 1,299 patients with 56 deaths, or an average of 4.45 per cent. Numerous researchers are actively engaged on the question at present, the causative agent has been studied particularly in America; it has been found that certain animals are susceptible to it, which gives promise of excellent results and of fine discoveries.

It is always interesting to have information on diseases which affect human beings in all countries; typhoid fever is of this class. In furnishing drinking water free from typhoid bacilli to numbers of people, the number of cases is very considerably diminished; but for those ill with typhoid, the mortality still remains high. We have had 1,522 patients and have noted 151 deaths, or 10.20 per cent.

In the army the anti-typhoid vaccination caused typhoid fever to disappear, which is a better showing than with the civil population which distrusts vaccination.

* * *

The Pasteur Hospital receives contagious patients, but as I have indicated, it is possible also to admit non-contagious cases, thus permitting studies of different diseases. We

mention syphilis, sleeping sickness among whites, spirochetosis ictero-hemorragica, and tetanus.

In the case of syphilis we have been the first to employ intravenous injection of Salvarsan, which proved to be very effective. Of 505 patients admitted there were 14 deaths.

Exotic Diseases. We have studied 957 exotic diseases, and more particularly sleeping sickness.

We have cared for 811 colonials, among whom were sufferers from malaria, sprue, and dysentery. In particular we have studied and followed up the cases of whites who had African sleeping sickness.

African Sleeping Sickness. For a long time it was thought that sleeping sickness did not exist among whites. We received our first such case in 1904; and since then we have examined more than 80 Europeans, coming principally from the Congo.

In the case of whites, trypanosomiasis develops frequently without evidence of somnolence, which is characteristic of that disease among negroes. That is what explains that, in many cases those suffering from the disease frequently went unnoticed for some time or were diagnosed at a late stage.

From our observations we have deduced some interesting facts on the origin, symptoms, forms, diagnosis, evolution, and prognosis of the disease.

We have, in particular, studied its treatment.

After experiments and numerous attempts, we recommend the treatment of whites by combining atoxyl and emetics.

We have indicated the dosage to be used and how to understand and avoid the obstacles that may arise.

We can tabulate the results obtained, if we divide into four parts the 80 first patients observed:

For the first 20, two patients survived;
For the next 20, one cure for every two patients;
For the third 20, the mortality was less than a third and for the remainder our results were even better still.

Spirochetosis Ictero-hemorragica. Following Inada and Ido and thanks to the contributions of the lamented Adrien Stokes, we have been able to treat several patients and have established the period of incubation as between six and eight

days. We have, also, recommended the study of specific agglutinius as a possible diagnostic aid.

Let us point out, in conclusion, that of 113 tetanus patients we had a mortality of 47.27 per cent., that is 54 deaths.

* * *

Up to this point I have indicated to you all the points that favor hospitalization by means of compartments, but I should not pass over the question of "interior contagion" (that is, spread of disease within the hospital); and I should like, also, to speak of budgetary matters.

Economic Study. First of all the economic function: the first establishment of a hospital for individual isolation costs more than hospitalization in large wards by about one-third. But in specialized wards, frequently the beds are not occupied and the personnel is at times too numerous and at other times nsufficient. In the Pasteur pavilion the beds are all occupied, rarely empty, and the expenses of up-keep are consequently much diminished.

Interior Contagion. To be thorough, I should point out what we have observed in regard to interior contagion. We appear to be protected fairly well, inasmuch as interior contagion has amounted to less than two cases per thousand. Of 37,671 patients treated, the contagions which we have observed most frequently have been:

7 smallpox,
32 measles,
4 erysipelas,
2 diphtheria,
10 scarlet fever,
8 chicken pox.

Thus, measles has been the most contagious disease. It was in the early stages of operation of the hospital that interior contagions were most frequent.

The personnel had to acquire experience, inasmuch as contagion resulted almost always from a mistake made by the personnel. These errors being avoidable, contagion diminished notably in the years following.

What I have just told you demonstrates that to care for patients, it is essential to have trained nurses instructed both theoretically and practically; it requires at least three years to train nurses who are to have charge of contagious diseases. The results that we have attained could not have been realized but for their zeal and devotion.

* * *

After this description which has resulted from 36 years of observation, I should like to say that it is a great joy for me to be able to join, in this celebration, the names of Benjamin Franklin and Pasteur.

Both had as their ideal to relieve our poor humanity.

Their efforts are known to all, and, to the general public, one is he who conquered lightning and the other he who delivered us from diseases which formerly decimated the population.

If France has the great privilege of being the native land of Pasteur, may I not assert that Benjamin Franklin is also one of us, for it must not be forgotten that he remained among us for eight years and regularly attended the meetings of the Academy of Sciences. Upon the resolution of Mirabeau, the National Assembly accorded him a tribute which, to that time, had been reserved for princes and kings.

I conclude this discourse by citing the principal passage of the resolution of Mirabeau:

"The Congress has decreed in the fourteen states of the confederation a period of mourning of two months for the death of Franklin and America is paying this tribute of veneration for one of the fathers of its constitution.

"France, enlightened and free, owes a debt of remembrance and regret to one of the greatest men who ever served philosophy and liberty.

"I propose that it be decreed that the National Assembly shall wear mourning during a period of three days for Benjamin Franklin." The Assembly adopted this by acclamation.

HUMAN HEREDITY AND MODERN GENETICS.*

BY

T. H. MORGAN, Ph.D., LL.D., D.Sc.,

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When I received an invitation to speak on this occasion for the biologists, I was puzzled at first why it was I who was chosen until a friend called my attention to an anecdote told by Franklin:

Some Madeira wine, that had been bottled in Virginia, had been sent to England. "At the opening of one of the bottles three drowned flies fell out into the first glass that was filled. Having heard it remarked that drowned flies were capable of being revived by the rays of the sun, I proposed making the experiment on these; they were therefore exposed to the sun upon a sieve which had been employed to strain them out of the wine. In less than three hours two of them began by degrees to recover life—they raised themselves upon their legs, wiped their eyes with their forefeet, beat and brushed their wings with their hind feet, and soon after began to fly, finding themselves in Old England without knowing how they came there."

Then, it became clear to me that it was my own interest in flies that suggested to some one that I might be able to explain the resurrection of Franklin's prodigies.

There are several explanations of Franklin's anecdote that have occurred to me—and possibly one that has suggested itself to all of you—But why spoil a good story by explaining it?

Any discussion of Human Heredity must emphasize the fact that man has a dual form of inheritance, one of which is peculiar to him and absent in all other animals. He inherits not only the physical attributes of his kind, but also, in a different way, the traditions of the race to which he belongs.

* Presented Friday afternoon, May 20, 1938.

The child learns partly by imitation, partly by instruction and individual experience, and with the beginning of speech and the invention of writing and printing the inherited racial traditions have come to play an all important rôle in the later evolution of mankind.

The question then arises whether the habits, that have been individually acquired by imitation or training, will be impressed on the brain of each individual to become later a part of his physical or shall I say his biological inheritance. This is a very old problem that began with the Greek philosophers. Four hundred years before Christ, the father of medicine, Hippocrates, advocated the view that each part of the body added its contribution to the male element of procreation, and thereby transmitted not only the racial characteristics of the male parent but also any additional individual characters acquired by the parent during life. This is the first historical record we have of the theory of the inheritance of acquired characters. Democritus, who lived at about the same time, held a similar view. It is not improbable that such views were widely disseminated in the folk lore of still more ancient peoples.

A hundred years later Aristotle discussed the problem pro and con, and on the whole rejected the view that each part of the body contributes something that goes into the make-up of the germinal material, but he seems nevertheless to have accepted the doctrine of the transmission of acquired characters in a more subtle way.

This doctrine persisted throughout the long period between 400 B.C. and 1800, i.e. for 2200 years, as Zirkle has recently emphasized. It was generally accepted even by the church fathers, and was again brought to the notice of the modern world by the well known French biologist Lamarck in 1806. Later it became a cardinal point in Charles Darwin's theories of evolution, whose hypothesis of pangenesis restated the ancient doctrine of Hippocrates. However, both Lamarck and Darwin made use of the theory in an entirely new way. They both tried to explain on its principles the procedure by which animals become adapted to their environments, and, as a result, they attempted to explain how evolution has taken place.

Seventy years after Lamarck, August Weismann (as had Kant before him) challenged the doctrine of the inheritance of acquired characters in his famous theory of the continuity of the germ plasm. In substance Weismann's theory postulates that the germ cells alone transmit the racial characters, and that the germ cells are neither produced by the body cells nor are they affected by the experiences of the individual. Weismann's view is generally accepted today.

There still remains the question as to what extent man's physical inheritance lies behind his ability to take advantage of the traditional inheritance of the group to which he belongs, and also by his inventiveness to extend his acquired knowledge into new fields.

To put the matter crudely: is the mind of the baby a *tabula rasa*—a blank slate on which its racial traditions are to be written; or are there black, white and yellow slates (and perhaps even pink ones)?

The answer is clear. If forefathers had themselves better brains at birth than the average there is a good chance that at least some of the children or descendants may have as good brains. This means that there may be black, white and yellow brains in the sense that one kind may be more inventive, or more receptive to one kind of training, and another kind to another kind of training. These qualitative differences may be small, but if they exist at the start the accumulated result of training may be very great.

This leaves out of account the possibility of the occurrence of greatly superior brains, which, so far as we know, may be only the result of happy combinations of all that is best in the race plus favorable opportunities for development; or, such superior brains may be due to the appearance of new types that transcend the original limits. We have no decisive answer today, but there is no reason to suppose that the physical evolution of man has come to an end; unless his physical evolution may be retarded or even suppressed by practices arising from his inherited social systems.

May I now turn to more technical problems in the general field of heredity, where the increase in our knowledge since 1900 has been extraordinary, and then consider the problem

as to how far we are justified in applying the same principles to the physical inheritance of man.

The most outstanding discovery is that of Gregor Mendel in 1865. He formulated two fundamental laws of heredity, the outcome of ten yeârs work on garden peas. Later the same laws have been found to apply to all other plants and to animals including man. Second only in importance was the discovery of the mechanism in 1902 by which this kind of inheritance is transmitted from generation to generation. Later still, two additional fundamental laws were discovered that we call the law of linkage and the law of crossing-over. These are also consistent with the working of the same mechanism that accounts for Mendel's laws. A knowledge of these four laws, and of the mechanism on which they are based, makes it possible today to predict exactly what is to be expected when combinations of different characters are brought together by the intercrossing of individuals.

It would take far more time than that allotted to me, were I to attempt to illustrate in detail these principles of heredity; but I may first say a little, about the mechanism behind these laws, and then, give a few examples to show how the mechanism applies both to human inheritance and to that of other animals.

Each species of animal and plant has in every cell of the body, including the reproductive cells, a definite number of staining bodies called chromosomes. In different species the number ranges from two to over a hundred.

When the reproductive cells reach maturity the number of chromosomes is reduced to half the full number. When the egg is fertilized by a spermatozoön the full number is restored. Hence the characteristic number for each species remains constant. It will be noted that half of the full number has come from the father and half from the mother. The child inherits equally from its father and mother; at least so far as its chromosomes are concerned.

Mendel's first law, the law of segregation, is explained on the chromosome mechanism in those cases where two contrasted characters (elements) are carried each in one of the members of a pair. This is illustrated by one of Mendel's crosses between tall and short peas. Mendel's second law, the

law of independent assortment, applies when two pairs of contrasted characters are carried in different pairs of chromosomes. This is illustrated by Mendel's case of a cross of yellow round and green wrinkled peas; and again by a cross between two color varieties of cattle.

It should be noted that Mendel's second law holds when the two pairs of characters involved are in different chromosome pairs. If this were the whole story there could be only as many types of inheritance as there are unlike chromosomes in each species. Something of the sort is true in general, for we know that the *elements* in a given chromosome tend to be transmitted together.

This is the law of linkage. For example: There are four pairs of chromosomes in Drosophila, and four linkage groups. All the characters in a group *tend* to be inherited together.

But it has also been found that an *orderly* interchange between the two members of homologous chromosomes takes place. This is the law of crossing-over—the breaking up of the linkage groups. A study of the behavior of the chromosomes, at the time when the chromosomes are about to be reduced to the half number, reveals the fact that such an interchange actually takes place. If a fly that has yellow wings and white eyes is crossed to a fly with gray wings and red eyes, then, in the second generation 99 per cent. of the grandchildren are like the grandparents, but 1 per cent. of the grandchildren are cross-overs with red eyes and yellow wings or white eyes and gray wings—they represent 1 per cent. of recombination of the two pairs of characters that went into the cross together.

Due to this kind of interchange it has been possible to discover the actual location of the hereditary elements in the chromosomes which has led to one of the most important developments in the history of chromosomal inheritance. The interchange involves large pieces of the chromosomes rather than individual elements. Two new linkage groups are established that are as permanent as those that preceded them. But these also are subject to interchange again at any level in a new individual in which they come to be present. The result is that in time all possible combinations of characters (elements) are brought about.

Now if crossing-over is as likely to take place at one level as at another in the chromosomes that are interchanging, it follows that the chances of crossing-over between pairs of elements will be greater the farther apart they lie in the linkage group. Conversely the nearer they are together the less often is crossing-over expected to take place.

On this hypothetical assumption the genes can be arranged in a map. The most complete map is that of the genes of the fruit fly Drosophila.

This procedure is not as arbitrary as it may seem, for it allows us to predict in what numerical proportion any new gene, that appears as a mutation, will be transmitted in relation to all other known genes.

And now I come to a still more recent discovery, one that, on a factual basis, explains another kind of inheritance. In this case an exchange or translocation may take place between different linkage groups or chromosomes. This discovery was made first from purely genetic evidence and has now been confirmed by a study of the chromosomes in the salivary glands of several species of flies. These glands are present in the larva. Their cells and their contained nuclei are enormously large. Also the chromosomes are large, as seen by comparing the ordinary chromosome group of the fly with those of the salivary chromosomes, which are nearly 200 times as long.

It was known, from genetic evidence alone, as I have said, that at times a whole piece of one chromosome may become detached and re-attached to another chromosome. It was also discovered that a part of one chromosome may be turned around—a reversal of the normal sequence of the genes. Nevertheless the characters of the fly containing such a translocation, or an inversion are in most cases identical with the original fly. This means that the sequence of the genes plays no important rôle in the make-up of a fly if it still retains the full complement of genes. It is true that, in some cases, minor changes may be introduced by detachments and reattachments of pieces of chromosomes, but it is a far-fetched argument to assert from this that the theory of the gene is overthrown.

More detailed work has shown a point to point relation between the genes and the bands in the salivary chromosomes. This does not mean necessarily that the bands are the genes, but it shows beyond reasonable doubt that the chromosome maps, built up on the genetic theory of crossing-over (it took twenty-five years to construct these maps) find complete verification in the maps of the salivary chromosomes.

Let me now point to a few cases that illustrate the application of the four fundamental laws of genetics to man.

In man there are blue eyed and brown eyed individuals. The children of a mating between blue eyed and pure brown eyed individuals have brown eyes. If now two individuals that have had this origin marry their offspring will average 3 brown to 1 blue eyed individual. The chromosome mechanism is here the same as that of the garden pea. The inheritance follows Mendel's first law.

The second law may be illustrated by the human blood groups. For several years it has been known that there are four kinds of individuals with respect to the kind of agglutinogens and agglutinins that they contain, and that these kinds are inherited in Mendelian fashion (three pairs of allelomorphs). More recently another pair has been found by Landsteiner and Levine that behaves as an independent pair. The combination of this latter with the former will serve to illustrate Mendel's second law.

There is at present one example at least of linkage in man. Haldane has shown that color blindness and haemophilia are characters that are linked in the sex chromosome. The same evidence shows at least one case of crossing over between these two pairs of linked genes.

The failure so far to discover more cases of linkage and crossing-over in man is due in part to the presence of 48 pairs of chromosomes and in part to the relatively few simple cases of inheritance in man. What is known, however, suffices to show beyond a reasonable doubt that the four laws of heredity and the mechanism of transmission are the same in man as in other animals.

There is a kind of inheritance in man known as sex linked inheritance that illustrates beyond a question that the

same sex determining mechanism present in other animals is also present in man. This sex determining mechanism rests on a difference in the chromosome groups of the male and the female. The female has a pair of X chromosomes; she is XX. The male has one X. Its mate is called the Y chromosome, which is practically empty so far as genes are concerned. He is XY. The ripe egg of the female has one X. There are two kinds of spermatozoa, one with an X, the other with a Y. Any X-bearing sperm fertilizing any egg produces an XX female. Any Y-bearing sperm fertilizing any egg produces an XY male.

Now if one of the X's carries a gene for a certain character, it is found that the inheritance of the character and the distribution of the sex chromosomes run parallel courses. The human pedigree for haemophilia gives exactly this kind of sex linked inheritance, and it is now known that the human male has an X and a Y chromosome and that the female has two X's.

Lastly I come to our star case which also brings us back to our starting point: namely, what we owe to nature and what to nurture, to use Galton's terms.

I refer to the occurrence of identical twins. Occasionally two babies are born that in their physical aspects are almost indistinguishable. Sometimes there may be three or four, and the quintuplets, of course. The resemblance lasts throughout life.

There is abundant though indirect evidence that identical twins come from one egg fertilized by one spermatozoön. Hence their physical inheritance is certainly the same. The twins furnish an opportunity to find out to what extent two identical brains will be influenced by the environment in which the training and traditions of the race will come to act on them; especially if the twins are reared apart. Studies of identical twins are now being extensively carried out, and when enough material is collected, and when better tests are found for measuring the intelligence and emotional resemblances and differences shown by such individuals we may hope to get very definite information as to what is owing to heredity and what to environment.

Someone may ask, what has all this to do with Benjamin Franklin? I think both the theory and the facts of modern genetics would have interested him profoundly, because numbers always fascinated him, and modern genetic work is based on precise numerical data. Again, I think he would also have been interested because he was attracted by mechanical devices, and the chromosomes furnish a mechanical explanation of heredity. And lastly I think he would have understood that modern genetics has an important bearing on population problems in which he showed great interest. As our theoretical knowledge of heredity increases, and as its application to the composition of human societies becomes clearer (it is already applied in animal husbandry and in agriculture on a large scale) its significance for the welfare of future society will be more widely appreciated; but the problem is, as I have pointed out, not a single one owing to the dual nature of human inheritance. If the transmission of the traditions of the race, its myths, taboos, customs and even its humanitarian weaknesses come in conflict with the laws of man's physical inheritance the former may at times delay further evolutionary advances of the kind that have brought man to his present status. And, on the other hand, the physical deterioration of the race, that may take place under the abnormal conditions of a complex and protected social life, can be prevented or ameliorated only by an intelligent understanding as to how such physical impairment takes place. The two sides of the problem of human heredity will constitute the future field of human engineering.

MUST ALL RARE PLANTS SUFFER THE FATE OF FRANKLINIA? *

BY

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In the autumn of 1765, John Bartram and his son, William, discovered near the Altamaha River in Georgia a splendid low tree or tall shrub which, raised in the Bartram Garden, proved to be a close relative of the Asiatic *Camellia*. So handsome were the richly fragrant white flowers, described as five inches across, that, in the words of Humphrey Marshall, "William Bartram, who first introduced it, . . . has chosen to honour it with the name of that patron of sciences, the truly great and distinguished character, Benjamin Franklin." Writing of it in 1773 William Bartram said:

"I have traveled by land from Pensylvania to the banks of the Missisipi, over almost all the Teritory in that distance between the Seashore & the first mountains, cross'd all the Rivers, and assended them from their capes a many miles, & search'd their various branches Yet never saw This beautiful Tree growing wild but in one spot on the Altamaha about 30 miles from the Sea coast neither has any other person that I know of ever seen or heard of it." [1]

Because of the great beauty and delicious fragrance of its flowers *Franklinia* was in great demand in horticulture. It is recorded that from 1787 to 1789 London nurserymen were ordering hundreds of plants from Humphrey Marshall and his nephew and partner, Moses Marshall. In 1790, the year of Franklin's death, Moses Marshall visited the Altamaha, presumably to fill commercial orders, and it is generally conceded that he was the last person to see *Franklinia* in its native haunts. Whether the wild shrubs and trees were then greedily exterminated by Moses Marshall for commercial gain or

* Presented Friday afternoon, May 20, 1938.

[1] From mss. at British Museum (Nat. Hist.) quoted by Harper and Leeds in Bartonia, no. 19 : 2 (1938).

whether the genus was already so near its natural end as a living tree that other factors closed its existence we shall never actually know. The bald fact is that Moses Marshall, in 1790, was the last man to see it growing where Nature had preserved it through millions of years.

Franklinia, as stated, is related to the Asiatic *Camellia*. It belongs in a natural family of shrubs and trees displaying the amazing disruption of range shown by hundreds of eastern North American groups which, in Cretaceous or Tertiary time, had a wide distribution across Eurasia and North America. Owing to the climatic and physiographic changes accompanying late Tertiary uplifts of western America and various parts of Eurasia, followed by the refrigerations of Pleistocene glaciations, these hundreds of groups have now disappeared from living floras except for disrupted remnants, sometimes in southeastern Europe, but more generally in southern and eastern Asia and in eastern North America. As long ago as 1750, Halenius, in his doctor's thesis defended before Linnaeus at Upsala, pointed out this similarity in the floras of eastern Asia and eastern North America, but it remained for the genius of Asa Gray to bring this relationship vividly before the scientific world.

Many closely related, if not identical species of this eastern or southern Asiatic and southeastern North American relationship are in no danger of extermination: such groups, for instance, as *Liriodendron*, the tulip tree, *Hamamelis*, the witch hazel, *Sassafras*, *Nyssa*, the sour gums, and *Symplocarpus*, the skunk cabbage. Others, however, after millions of years of competition with more youthful types, have retained such tenuous footholds in America that they are rightly looked upon as last remnants of the ancient flora which have grown old where they now linger but which lack the capacity to resist the invasions of more youthful or aggressively dominating genera and species, and least of all the invasion of "that most destructive of all creatures, 'man.'" [2] Many of them are the rarest of plants and some of the most remarkable have already suffered the fate of *Franklinia*.

In order to make quite clear the varying capacities to meet present conditions of plants in the wild (and, I take it, a

[2] Scharff, R. F., "Distribution and Origin of Life in America," 194 (1912).

parallel grouping can be made of mammals, birds and lower groups of animals) it is necessary briefly to consider the composition of the wild flora of eastern America. To the layman the words plants and flora too often mean garden flowers, farm crops, timber trees and weeds. These, although the most obvious of plants, are to the thoughtful student the least interesting, unless, perchance, his outlook is strictly pragmatic.

By far the most familiar element in our wild flora in the neighborhood of old settlements is the great population of weeds. Brought chiefly from the roadsides, fields and waste lands of Europe within the last three centuries, they are covering the disturbed soils of large sections of the North American continent: common dandelion, burdocks, daisy or white weed, witchgrass, mustards, hawkweeds, wild carrot, Canada thistle, bull thistle, common plantain, English plantain, pigweed, docks, smartweed, and many others, including the various cultivated (and escaped) fodder plants, like the clovers, timothy and orchard grass. The invasion of newly disturbed or cleared land by the hawkweeds (Devil's paint brush, king devil and others), dandelion, witchgrass and others of their ilk is too obvious. They are the youngest species of our flora, the rapidly reproducing, aggressive, uninvited and unrestrained vagrants, the ultra-democratic and unsophisticated intruders. Their number is well over one thousand and their army is reënforced by every arrival of uncleaned European seeds, in the stockings, trouser-bottoms, skirt-hems and blankets of immigrants, in the litter and old straw used in packing from abroad. Arrived in a new country they know no restraints and after a short period of adjustment become the bulk of our plant-population wherever natural conditions have been destroyed, and they will even invade and obliterate relic-colonies of our original native flora.

There is no possible question of the present-day biological success of the introduced weeds. When I was a boy in Maine, in the late 70's and early 80's, one of the beautiful garden perennials, raised in a few favored borders and coveted by all who had flower-gardens, was *Hieracium aurantiacum*, a plant with broad clusters of orange and scarlet tassel-like erect heads. It was handsome and at that time unusual and it was scrupulously shared only with those who would really appreci-

ate and nurture it, as Venus' paint-brush. Soon, however, in the 80's and early 90's, it had become acclimated and began to appear in the fields. It has now ruined thousands and thousands of acres of fallow field and clearing from the tip of Gaspé to Michigan and southward to Pennsylvania; and, whereas it first came to America as Venus' paint-brush, it is now known to all farmers as Devil's paint-brush.

One of the handsomest plants of pastures, hillsides and open mountain-slopes of the British Isles is a large groundsel (*Senecio Jacobæa*), known as ragwort or by fifty other local and colloquial names. One of its older cognomens was the dignified St. Jame's Wort (whence the Latin name). In the late 70's St. James's Wort appeared as a waif or stowaway on ballast, thrown out from a ship at Pictou, Nova Scotia. For several years it remained a local colony; but by 1884 it had begun to spread along the local roadsides; by 1900 it had become one of the worst pests of northern and eastern Nova Scotia, eastern New Brunswick and Prince Edward Island. Browsing animals avoid it and it has full sway, completely dominating, along with one or more of the European hawkweeds, much of the cleared land of the Maritime Provinces, where no one now calls it St. James's Wort; it is everywhere appropriately known as "Stinking Willie." Soon after 1900 Stinking Willie reached the waste land about the union station in Portland, Maine, and it now colors a pasture-slope in Essex County, Massachusetts.

One of the most remarkable elements of the flora of eastern North America is the estuary plant, a few very distinct species which grow only on the flats of rivers where twice a day the incoming tide pushes back the fresh or but slightly brackish waters. Only a few species can tolerate the rapid changes from drowning and immersion in mud and silt, alternating with drying-off or toasting in the sunshine. Consequently the distinctive estuary species are a restricted and biologically significant group. The finest estuary in our region is that of the St. Lawrence, from slightly below Montreal to many miles below Quebec; others of note are the estuaries of the Penobscot, the Kennebec-Androscoggin system, the Merrimac, the Hudson and the Delaware. Twenty years ago any of these estuaries would yield abundant ma-

terial of their endemic (or epibiotic) species. But Montreal became a great fresh-water port for transatlantic liners. Straw and litter from Europe thrown into the St. Lawrence quickly found lodgment and the seeds or tubers of meadow plants of England and France discovered a new home. Today for many miles, from above Montreal to below Quebec, the formerly unique and endemic flora of the estuary is being rapidly obliterated by the crowding and handsome but overwhelming flowering rush (*Butomus umbellatus*) and the purple loosestrife (*Lythrum Salicaria*), both gorgeous to look upon but unscrupulous and without mercy for the insignificant endemics, which cannot last many years longer. Similarly, on the lower Merrimac the same purple loosestrife, a joy to the artistic and unscientific eye, has obliterated the fastidious and localized endemics, which had become isolated there since the last withdrawal of the Champlain sea.

Unfortunately, these vagrant, aggressive and opportunist weeds from Europe are destined to be the cosmopolitan flora of temperate regions as soon as man has a little further interfered with the natural habitats of our long-established native floras. They are our thoroughly successful wild plants and their success is to be compared only with that of the European man, the European rat, the European mouse, the European house (or "English") sparrow, the European starling, the European gypsy moth, the European brown-tail moth, the European house fly, and other invaders which, wherever they can get an opening, are rapidly replacing our indigenous Indians, rodents, birds and insects which had long ago established an equilibrium.

In our native flora, likewise, there is a group of aggressive invaders, certain plastic and pioneering species which, along with the vagrants of European origin, often take possession of newly cleared or disturbed land: pasture brake, fly-away grass (*Agrostis scabra*), aspen (*Populus tremuloides*), gray birch (*Betula populifolia*), hardhack (*Spiræa tomentosa*), wild strawberry, raspberry, blackberries, bird cherry, yellow ladies'-sorrel (*Oxalis europæa*), poison ivy, fireweed, pennyroyal, horseweed and a hundred more. These are our native invaders but they are relatively harmless. They have been longer on the ground and, although showing some of the

unrepressed traits of aggressive youth, they are surely less obnoxious in their behavior than are many of the recently arrived European invaders.

Then there are the dominant but unaggressive species, abundant over vast areas but showing little or no tendency to push in where they are not wanted: cinnamon fern, various clubmosses, ground yew, Indian poke, bayberry, hazel, beech, common clematis, columbine, sugar maple, and hundreds of others. These are the common species of appropriate wild habitats, the backbone of our flora, the bourgeois, vigorous, fertile, dependable, chiefly of late Tertiary dispersal and eminently respectable.

After them I should place the quiescent species, locally abundant over large areas, absent from equally extensive areas: maidenhair fern, adder's-tongue fern, shag-bark hickory, marsh marigold, blood-root, climbing bitter-sweet, wicopy or leather-wood, ginseng, bottle gentians, fringed gentian and three or four hundred others. These are the plants familiar to everyone in certain areas, quite unknown in other areas, conservative as to habitat, holding their own and prospering under the conditions they have always known. Following the social classification adopted, they might be called the upper middle class, too fastidious to be "go-getters" but with enough vitality and reproductive capacity to prosper where conditions are favorable. This conservative but prospering element in the flora consists largely of genera or subgenera which have the interrupted eastern Asiatic-eastern American range. Whenever fossils of these groups (*Adiantum*, *Chamæcyparis*, *Carya* (hickory), the hornbeams, the black birches, *Celastrus*, *Tilia*, etc.), have been found they indicate a general occurrence in Tertiary time (sometimes Cretaceous) over the Northern Hemisphere, often including areas which are now the Arctic. It is significant, therefore, that these plants of considerable antiquity have largely lost the pioneering capacity of younger types.

Then come the various groups of local species, plants of wide general range but always with restricted areas, not abundant over large tracts: *Isotria affinis*, the small whorled pogonia, *Cypripedium arietinum*, the ram's-head lady's slipper, *Trollius laxus*, globe flower, *Polygala brevifolia*, *Polemonium*

Van-Bruntiæ and many more. *Isotria affinis* has altogether about a dozen known stations, scattered from Virginia to Maine. Its northern outliers are a patch of 35 plants in Oxford County, Maine, one of a few individuals in central New Hampshire, and one of a single individual in northwestern Vermont. These plants are exclusive, undemocratic as to their associates and show the social isolation and the limited reproduction of the aristocracy.

My chief concern today, however, is not with the ultra-democratic intruders from Europe nor the bourgeois, the upper middle class nor even the lesser aristocrats in our indigenous flora. My plea is for whole-hearted protection of that helpless but tremendously interesting group which may be called the fugitive aristocrats, the completely isolated and usually quite overlooked small colonies, doing no one any harm but of utmost importance to the student of life and its history through the last 100,000,000 years. Benjamin Franklin was himself a democrat, but *Franklinia*, named in his honor, was a fugitive aristocrat. Even if we try to overlook the commercial implication of Moses Marshall's last visit to the refuge of *Franklinia* on the Altamaha, it is perfectly evident that the unrestrained pressure of bourgeois and vagrant species about it and the unintelligent intrusion of aggressive man would soon have wiped it out. Its fate has been that of hundreds (no one can guess how many) of relic-species and a similar fate threatens the whole series of highly localized rarities.

The limestone ledges of Rock Island at the Falls of the Ohio near Louisville, Kentucky, and New Albany, Indiana, were, a century ago, the home of a remarkable number of highly localized plants. At least two of them have never been found elsewhere. One was *Psoralea stipulata*, the other *Solidago Shortii*. Each is a unique species, the *Psoralea* so peculiar that our most intensive student of the group has doubted [3] whether it is a *Psoralea* at all or whether it may belong to a wholly different tribe. The solution depends upon securing fruit of the plant, which is now out of the question. "Rock Island . . . was blasted away some years ago when the Ohio was made more navigable." As to *Solidago Shortii*,

[3] See Rydberg, "Torreya," xxvi.89 (1926).

the layman would say "What of it? It is merely another goldenrod of which there are already too many." But consider a moment. When Edison started his studies of new sources of rubber he had as botanical advisor the late Dr. John K. Small. Shortly before his death Small told me that, of the hundreds of species of quickly growing plants which might serve, *Solidago Gattingeri* had been found to give the greatest yield of rubber. To the layman, again, *Solidago Gattingeri* is merely another goldenrod; to the economist it is a most promising quickly grown source of rubber; to the student of the flora it is a highly localized plant of a few limestone glades and knobs of Tennessee and adjacent Missouri. Luckily for the future of the rubber-industry this goldenrod had not been exterminated before its economic importance was discovered! Incidentally, where would man and his civilization be today had not our "primitive" peoples of the past rescued, before their extermination in the wild state, such seemingly indispensable cereals as wheat and maize (Indian corn)? Who, in our present rudimentary state of intelligence, can predict what rare, localized and usually overlooked species has economic possibilities?

Instances of the destruction of the last or only living colonies of other rare plants by the blasting away of ledges or the building of dams will occur to every experienced field-botanist; and the pollution of rivers by strong chemicals from pulp-mills and factories has been as fatal to the native flora of river-gravels as to the salmon, shad and other important fishes of the river-channels. Some of the most amazing of plants grow only near rivers. On the upper St. John, between Maine and New Brunswick, there is a unique species of wood betony, *Pedicularis Furbishiæ*, named for its discoverer, Kate Furbish. Under the manufactured "English name," "Miss Furbish's Lousewort," it does not sound very interesting. Its only close relative, however, is on the other side of the world, in the mountains near Lake Baikal in southern Siberia. It is, then, one of the most telling evidences that life on the upper St. John was not wholly destroyed, as we were taught, by Pleistocene ice. To the student of biogeography it is a most important plant. Luckily, no factories, vomiting poison into the river, have yet been built up-river from it. Let them once

start to pollute the waters and then develop a freshet to overflow the banks; immediately the last plant of *Pedicularis Furbishiæ* will die and this living witness to the past wide dispersal of its group will be gone.

Another danger to plants of river-gravels is the mechanical one of log-driving. In 1905, on one of the Gaspé rivers, my companion and I found, among other extraordinary plants, a half-shrubby strawberry, *Fragaria multicipita*, with many erect long-lived fruiting branches but no slender runners, such as a conventional strawberry plant should have. It is not closely related to any known species. Near it was a single small colony of an equally remarkable willow, *Salix obtusata*, a shrub which the great monographer of the willows, Dr. Camillo Schneider, can relate to no living species. Twenty years later, taking a party of botanists to see these two unique plants, we found that the heavy teaming of a logging crew and the use of the beach as a lumber-camp had quite extinguished the two unique plants. None but the botanist mourns the loss of these species; their burial-ground is now covered with aggressive weeds of European origin brought there by the lumber-crew.

Another notable plant, partly destroyed by the activity of man, aided perhaps by Nature, is the handsome mallow, *Phymosia remota*, related only to plants a thousand miles or more away. Originally known only from a gravelly island in the Kankakee in Illinois, the species suffered from its distinguished beauty and its shifting habitat and there eventually became extinct. In 1927 a second station for it was found more than 450 miles to the southeast, in western Virginia, a region originally rich in these highly localized species. In the Virginia habitat "the individual specimens grow vigorously and attain a height of 6 feet or more. . . . Although there is an abundant supply of seeds each year, reproduction seems to be at a low ebb for there is apparently no spread of the plants and the number during the years from 1927 to 1931 has remained fairly constant, the total number at the present time being not more than 50." To be sure, brought into the garden and given artificial aid in germinating, *Phymosia remota* succeeds. But in its natural habitat, which alone interests the student of historical phytogeography, it is constantly in

danger of a raid by some over-zealous and commercially minded seeker for rare plants for the garden.

Three other highly localized relic-endemics must be mentioned. Among the most remarkable descendants of the ancient flora which once girdled the whole northern hemisphere is the beautiful yellow-flowered shrub, *Kerria japonica*, brought from eastern Asia to our gardens. But *Kerria* has a very close ally lingering at the southern margin of the Appalachian Upland. At a single spot on the cliffs of Black Warrior River, near Tuscaloosa, Alabama, *Neviusia alabamensis*, like an apetalous *Kerria*, was discovered in 1858. It is a dramatically interesting and biologically most significant plant; and no one has ever found another colony of it. Let an impulse to blast away the cliffs lead to fatal action, some one may become momentarily richer thereby but *Neviusia* will be gone. In 1934 Mr. Bayard Long and I found a singular plant in a very restricted bit of peat near large fresh-water ponds in Princess Anne County, Virginia. Unlike anything known to us, it eventually proved to be a member of *Hypoxis*, subgenus *Ianthe*, of the Australian region and South Africa. One other member of *Ianthe* occurs as one of the very rarest of plants in the Southeastern States. Otherwise the group belongs in the antipodes. To the botanist the little colony of *Hypoxis Longii* in Princess Anne County is of great significance, as one of the living descendants of the flora of Cretaceous dispersal which reached Australia before it was cut off from connection with other lands. It was discovered in 1934; it prospered in 1935; but in 1936 word came to me that the neighboring ponds were being drained and the *Hypoxis*-area ditched—the inevitable end of *Hypoxis Longii* and its endemic and relict associates! In fact, deep ditching and consequent lowering of the water-table, such as the powers that be have extensively carried forward on the Atlantic Coastal Plain, spells ruination to the highly specialized and sensitive descendants of ancient stocks which, undisturbed, have been able, until the advent of the White Man, to hold on in specially favorable spots. Incidentally it is ruining the breeding- and feeding-haunts of the vast group of organisms, both animal and vegetable, which have always lived together and depended upon one another. Recent pages

of journals devoted to the saving of natural conditions are replete with such facts.

As a last illustration of what science has lost and is helplessly losing I will mention a little wintergreen whose ancient home has literally become a grave-yard. Throughout the vast order *Ericales* or heaths, a world-wide group, the anthers are erect, except in *Pyrola* and its allies. In this group, differing from the others in its herbaceous instead of woody habit, the anthers in bud are erect and extrorse (opening outward) but in the opening flower they become inverted so that their morphologically basal pores are at the top, the morphologically uppermost points at the bottom, and their dehiscence is introrse instead of extrorse. All over the Northern Hemisphere *Pyrola* is consistent in reversing the direction of its anthers; but, apparently, it used to have them as in the ancient woody heaths. In 1860, the late Coe F. Austin discovered on a wooded slope in the Delaware valley a most amazing *Pyrola*, which he described as *P. oxypetala*. In leaves and petals it is unlike other species of the genus but, strangest of all, it has the mature anthers erect. Unfortunately, this remarkable and only known link between modern *Pyrola* and the ancient heaths has never been rediscovered; but, fortunately, Dr. Austin preserved good material of it. Many botanists have sought it and I have personally had a try for it. The locality best fitting Austin's account is now a suburban cemetery, with carefully scraped and groomed banks and landscaped effects, with everything possible done to discourage a native plant or animal of fastidious habits and specialized requirements.[4] The people of the neighboring city do not care; they never heard of *Pyrola oxypetala*. It has nothing to do with their lives and where it originally grew they have a conventionalized or standardized area in which to lie after their earthly careers are finished. *Pyrola oxypetala* would have seemed an insignificant "weed" to the landscape architect who wanted foreign plants put in its place.

Right here is the most serious problem for those who regret the unnecessary destruction of our sensitive and retiring species of plants and animals. For it has been too much the custom to overlook the fact that the oldest and most interest-

[4] In case of *Pyrola* dependence on mycorrhiza.

ing of animals and plants are what I have called the fugitive aristocrats. These are the rare and ecologically most retiring and specialized species, known only to a few special students of a region; and anything which upsets the equilibrium to which, through millions and millions of years, they have gradually become adjusted, is fatal to them. If the experienced botanist were first consulted no conventional planner of man-made landscape and unintentional destroyer of these inconspicuous relict species and of Nature's equilibrium would have a place on any board which is to control the destinies of preserves for wild life. When I first knew eastern Massachusetts many public-spirited citizens gave freely to the state wild forest-lands for state reservations which were to be kept forever wild. The project was put into the hands of a Commission, with a distinguished landscape architect at its head. To the Commission the maintenance of wild, natural conditions was indeed a "project." Original donors of land and lovers of Nature protested in vain. Undershrubs were cleared out, destroying the nesting haunts of various native birds; the dead leaves, which supply the humus for many rare plants and the hiding places of many small animals, were raked up; and everything unwittingly done to make the areas forbidding to sensitive and retiring species.

Naturally, we cannot expect all so-called human progress to be held up because Nature is in the way. Man's mastery over Nature is one of his proudest boasts. The highly trained and often over-cultured landscapist is in one respect only a step removed from the unschooled French Canadian habitant. The latter will cut down, with almost religious fervor, his enemy, the native forest; then, almost instantly, he will plant foreign trees and shrubs about his church and home! So long as man has the passion to alter the perfectly balanced conditions of life which Nature, through countless ages, has developed, the rare and retiring plant or animal has no more chance of survival than has the human fugitive aristocrat in the dictator-ruled countries which are so upsetting to lovers of human liberty. Let the conventionalizer of landscape confine his useful art to areas which may appropriately be conventionalized and where Nature is admittedly "conquered" by man.

The plights of the bison, the prairie hen, the Labrador duck, the passenger pigeon, the great auk and scores of other birds and mammals are familiar. Our last refuge of the great auk or penguin was Funk Island, off the coast of Newfoundland. There it was far from settlements; but Nordic fishermen, realizing the wickedness of fishing on the Sabbath, spent their Sundays on Funk Island and gave exercise to their fervor by clubbing to death the last remnants of these ancient and primitive birds. This wicked slaughter can in no way be attributed to their resentment that Anatole France in "Penguin Island" had ascribed human attributes and human souls to these dignified birds. The slaughter was finished before the publication of "Penguin Island."

On the last day of March of this year the papers in Massachusetts contained an invitation for citizens to visit the forests denuded and altered through wholesale effort, unfortunately misbranded "conservation." I quote from the *Boston Transcript* of March 31: "'The camps that have had 65,000 boys . . . at work . . . ought to be worth a visit . . . These boys have sent $14,000,000 to their homes . . . besides the money reserved by them for their own personal use. They have done a good job, for I am told that the CCC has advanced conservation eighty years.'

". . . there will be boys on duty at the barracks to receive the public and to show visitors through the forests to see new ponds, roads, bridges, beaches, water holes and new plantings."

Now think carefully for a moment. The building of artificial ponds, roads, artificial bridges, and artificial beaches and the planting of introduced trees and shrubs is not conservation. It is just the opposite of true conservation, for it upsets the natural equilibrium which had become established long before man, pround of a supposed resemblance to God, came to ruin it. True conservation [5] leaves Nature, mother

[5] In view of the evident misinterpretation of the meaning of "conservation," as evidenced by numerous comments in papers and magazines and in scores of personal letters received by the writer since the delivery of this paper, it is well to quote from the Century Dictionary:

conservation . . . [. . . L. *conservatio* (*n*—), < *conservare*, pp. *conservatus*, keep: see *conserve*, *v*.] 1. The act of conserving, guarding, or keeping with care; preservation from loss, decay, injury, or violation; the keeping of a thing in a safe or entire state.

of us all, uninjured and the true conservationist is a lover and defender of uninjured Nature. According to the quoted report, misguided but loyal and enthusiastic young men had been paid in a single state more than $14,000,000 of the tax-payer's money for making the face of Nature unnatural. The Sabbath-day executioners of the great auk turned their particular methods to account through profit from the oil. Moses Marshall and his uncle, Humphrey, got their price for presumably exterminating *Franklinia*.

If vast regiments of otherwise unemployed young men are to be encouraged to hew, rake and alter the forests, they will unconsciously become destroyers of the natural equilibrium of Nature. Put them to work destroying the vagrant pests which crowd us and which are a worthy foe. Our open lots and roadsides are overrun with ragweed, the most prolific cause of hay-fever, as well as by poison ivy, tent-caterpillars and scores of other nuisances. No one really cherishes ragweed; but it is a formidable task for a few individuals to clear it all up. It is a quick-growing annual and by concerted action a little of the tax-payer's money could appropriately go to its eradication or to the reduction of poison ivy or of tent-caterpillars. Or consider the Japanese honeysuckle. So long as it is kept in restraint this Asiatic migrant is a handsome vine; but it has invaded the Southeast like a hoard of Huns. Everywhere from the Gulf States to Long Island this rampant and unrestrained twiner is strangling the native vegetation. It has become what I have elsewhere called the Yellow Peril of the South. Its destruction would be a notable achievement. Its continued toleration is a menace to the native plants and animals.

I have preached enough. The problem is most difficult. The country is awakening, we hope, to a belated appreciation

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conserve . . . 1. To keep in a safe or sound state; save; preserve from loss, decay, waste, or injury; defend from violation: as, to *conserve* bodies from perishing.

As soon as man, or his implements, disturbs the long-established interrelation of organisms in the wild he innocently but, nevertheless, effectively prevents the *conservation* of these delicately interrelated animals and plants. In the brief space available this important question can hardly be expanded. The spread of youthful and aggressive "weeds" already referred to and the destruction of the feeding-grounds of shore-birds are pertinent illustrations.

of its precious birthright, now largely wasted. Lovers of birds and mammals have made the right start. Lovers of the rare and scientifically most significant plants urge that all rare native species be given a real chance.

The words of the 16th century herbalist addressed to his patron, "the right Honorable his singular good Lord and Master, Sir William Cecil Knight," conveyed in the stilted and elegant style of the period the healthy attitude:

"Among the manifold creatures of God (right Honorable, and my singular good Lord) that have all in all ages diversly entertained many excellent wits, and drawne them to the contemplation of the divine wisdome, none have provoked mens studies more, or satisfied their desires so much as Plants have done, and that upon iust and worthy causes: For if delight may provoke mens labor, what greater delight is there than to behold the earth apparrelled with plants, as with a robe of embroidered worke, set with Orient pearles, and garnished with great diuersitie of rare and costly iewels? If this varietie and perfection of colours may affect the eye, it is such in herbs and flowres, that no *Apelles*, no *Zeuxis* euer could by any art expresse the like: if odours or if taste may worke satisfaction, they are both so soueraigne in plants, and so comfortabel, that no confection of the Apothecaries can equall their excellent vertue. But these delights are in the outward sences: the principall delight is in the minde, singularly enriched with the knowledge of these visible things, setting forth to vs the inuisible wisedome and admirable workmanship of almighty God."

IT'S CALLED ELECTRICITY.*

BY

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It seems regrettable that a man who has spent half a century in close contact with electrical experiments should have to confess ignorance as to just what electricity is!

I have even been told by competent friends that I ought not ask what it is! And yet, I reflect, having in some way collected a knowledge as to what water is, what copper is, and even what faith is, why need I remain so ignorant when it comes to such a common thing as electricity?

I consult history and learn that for centuries of unaltered viewpoint, electricity was known as a spirit, and because spiritual affinities and human affections were obviously correlated, magnetic powders were prescribed by physicians to increase the attractiveness of unattractive people.

It was not till the days of our own Benjamin Franklin that electricity became one or two kinds of fluid. Fluids seem a little more tangible than spirits, and electricity became quite tangible with Franklin. By simply touching a container he could tell whether or not it was charged with electricity. But with more refined criteria, the fluid idea had to be given up. Electricity acts more like a gas in some cases. Later the gas idea too was inadequate.

The only safe way with electricity is to expect a new picture whenever new tools for better measurement are discovered.

In choosing the title I was guided first by my admiration for Franklin. I am happy in the thought that he was not seriously troubled, as I have been, by not knowing the "why and wherefore" or the quintessence of the things that his experiments taught him. The important point is: he applied what he learned. In many fields he was a most interested and

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inquisitive investigator, and no one ever enjoyed his occupation more. He simplified observations by pictures, as we do, but, having learned what regularly followed experiment, he encouraged his mind to bring the consequences not only within the range of expectancy but also of utility. This led him, as he wished, into continued productivity. There was no cluttering of his mind with metaphysics, or a futile search for primal essences.

I feel sure he read and liked Francis Bacon because Bacon too sought utility so energetically. While Franklin enjoyed his theory of fluid electricity exactly as we do our own pictures of intangibles, he enjoyed no less the experiment through which he materialized the lightning rod.

A more useful reason for my address is interest in youngsters and a feeling that they may be worried, as I have been, by quite harmless scientific bugaboos. I would like to encourage boys to realize the flexibility of electricity. Fortunately it is difficult to draw a perfect picture of any inside mechanism of Nature. Electricity is no exception. Everyone who has tried it has had his picture well painted over by later artists. On the other hand, the results of even the simplest experiments remain unaltered, and so constitute the permanent assets. This doesn't mean that pictures are useless. They are valuable catalyzers and are enjoyable. I'd like to encourage and embolden the inquisitiveness of youth. I don't wish to be didactic, but I'd suggest that we are limited in our conceptions by the inadequacy of our words and so cannot express the infinite complexity of reality. It is this want which sends our imagination out in search of ideas not yet wordable. This natural, beneficial provision is a wonderful tool, but not an end in itself. Even imperfection of our old words is a boon to science. For example, the moment someone suggests that gases are just a hustling crowd of anything whatever, some interested scientist applies his individual conceptions of "hustling," "crowd," or of "anything whatever," to see if they fit the picture, and then he tries an experiment and learns a new fact. It may be futile to express any essence in words, but it is distinctly useful to try it. Words have in them plenty of inherited characteristics, and, even if perfect for past events, they seldom quite fit the unlimited, novel phenomena

of nature. This explains the painfully gradual growth of our scientific vocabulary.

I look on Bacon and Franklin as men who saw the need of gregariousness (I'd even say happy garrulousness) in science. New phenomena which occur constantly must be appreciated, described, perpetuated and used. This means gathering and getting together in more ways than one. So Bacon, about 1600, publicly advised the banding of scientific men to coöperate in research, "For the real and legitimate goal of the Sciences (as Bacon expressed it) is the endowment of human life with new inventions and riches."

Clearly as a consequence of his tireless advocacy, a practical proposal for an institution of experiment was published in England shortly after Bacon's death, and in 1645 well known scientists modestly undertook inquisitive coöperation as he had suggested. This group, which developed into the Royal Society of Great Britain in 1661, has been usefully quizzing the unknown ever since.

Thus I connect to the efforts of Bacon that proposal of Franklin's published in 1743 which led to the establishment of The American Philosophical Society. In fact, we read in Franklin's proposal "That a correspondence already begun by some interested members, shall be kept up by this Society with The Royal Society of London," and he offered to act as the first secretary.

I quote also from a letter of Franklin's written 40 years later to Sir Joseph Banks, president of The Royal Society: "Furnished as all Europe now is, with academies of science, with nice instruments and the spirit of experiment, the progress of human knowledge will be rapid and discoveries made of which we at present have no conception. I begin to be almost sorry I was born so soon, since I cannot have the happiness of knowing what will be known 100 years hence."

This is not an explanatory review of electricity but an attempt to encourage further questioning and experiment, particularly by youth because the elders are preoccupied. We should let our imaginations work and forget the critics of ideas. In 1747 Franklin wrote to members of The Royal Society explaining his new view of the identity of lightning with electricity—a view that came from his experiments.

One of the members of the Society read Franklin's conclusions before that august society and reported that "it was laughed at by the connoiseurs." But ten years later the members were glad to elect Franklin to membership.

I am not so much interested in impressing you with Franklin's view of the static electricity in cats' fur and of Jove's Thunderbolts, however, as I am in pointing out that his vivid imagination, freely expressed, put lightning rods on buildings. And they are there yet. From noticing the peculiar effectiveness of his knuckle in discharging Leyden jars, his ideas soared into the clouds, so to speak. So he broadcast his new idea, saying, "May not the knowledge of this power of points be of use to mankind in preserving houses, churches, ships, etc., from the stroke of lightning?" Most of us are more conservative and fearful than that. This was no exceptional case with Franklin. His mental flexibility included balloons, and 150 years ago he received the world's first air-mail letter after a balloon carried it across the English channel.

At this point, since I have in mind following some of the lines along which appreciation of electricity has taken place, regardless of electrical quintessences, I confess with Franklin that: "I find a frank acknowledgement of one's ignorance is not only the easiest way to get rid of a difficulty, but the likeliest way to obtain information; and therefore I practice it and think it an honest policy."

I want to be exact in dealing with electricity, but also imaginative, in order to encourage myself and others. Conceptions of electricity will continually change by expanding, as they have always done. Indeed, expansion is a most marked property of electricity. Even the smallest trace of it, an electron, may exert influence anywhere. The motion of a speck of electricity in San Francisco is felt in New York, whether it goes by wire or wireless.

Sometime ago I reflected that if electricity is anything tangible, or like a liquid, it should be possible to put some of it onto a rubber balloon, and, by having the same kind on two balloons, show the repellent forces of similar charges and the attraction of unlike electricities.

I connected two metal plates, charged respectively positive and negative, to a source of 200,000 volts d.-c. After making repeated contacts between the plates and the balloons, I was satisfied that balloons could never be charged that way. But I explained my difficulties to Dr. Coolidge, and in a short time he succeeded. He charged the balloons by rubbing them on his hair. Thereafter, but not before, I could easily explain this solution by visualizing conducting films of moisture put onto the otherwise dry balloon from the hair which in turn conducted so-called frictional electricity over the surface. The balloon experiment illustrates a simple, unexpected and encouraging use of the head. The ancient experiment seemed a sort of clincher for the assumption that, whatever electricity really is, there are two and only two kinds, equal and opposite. Franklin called them positive and negative. But negative electricity sometimes acts much more positively than does positive. A radio tube would be quite a different thing if this were not the case. Attempts have been made to represent all the facts by accepting one kind of electricity only. I have always wished that could be arranged. Electricity would then be but one thing. Ordinary so-called neutral matter might be arrangements of that thing, electricity, with or without anything else. The absence of the thing from matter would leave us something new, or, possibly, nothing at all.

One of the beautiful things about electricity is that experiments forever show new and unexpected things. Before the discovery that the smallest bit of electricity is a negative electron, the professor, explaining a carbon arc lamp at school, had different ideas. A very highly magnified image of the arc left us with the impression that the current across the gap between the arc-terminals consisted of positively charged particles. Later I once tried to prove this by measuring the loss of weight of different kinds of arc-terminals. These losses were enormously influenced by position in space, because electrode-burning also took place. If any positive carbon crossed the arc gap, I failed to prove it. Experiments were tried using inert gases and vacuum. There one electrode often lost weight while another gained. But this was apparently due to simple sublimation.

I passed electricity across gaps between gold, platinum and other electrodes and even submerged them in water, hoping to eliminate effects of temperature-difference and combustion. But the results were very erratic, and I could determine no electrical migration of matter through any arc. Such simple experiments are always interesting, and the results themselves remain true. Freshly painted pictures of what goes on—that is, our imaginative conceptions—are important because they lead us to look still further and see better. We visualize now that what goes on in arcs is very complex. From the neutral vapors in the arc-path, and from electrons of the cathode, are derived various ions, metastable and excited atoms. These latter, in returning to electrical stability, send out radio energy in definite wave-lengths, and their wireless messages constitute the colored lights, spectra of the chemical elements.

Passage of electricity through arcs differs considerably from the passage of electricity through solutions. Like ferry-boats, suspended particles of most substances carry electricity across a watergap. This resembles what occurs with many but not all dissolved substances. Such migration is seen, for example, in the motion of the blue color of dissolved copper in electrolysis. Here the atomic ferry-boats are parts of salts or so-called polar bodies. Dissolved sugar, for example, does not do this, but salt does. This seems simple compared with arc-phenomena.

In case of solutions, the generation of electrical energy by batteries, which historically preceded the electro-magnetic method, fits present views of the structure, nature, tangibility, etc., of the thing called electricity, and lets us distinguish between it and its effects. Most present chemical elements, being differing collections of electricity, are stable enough to persist alone, but are often capable of reaching greater stability by mutual reaction. What one element has in excess, another may relatively lack. Under this condition they may send the difference in electricity through a solution. In a Daniell cell, we say that copper comes out and zinc goes into, solution, because of their different atomic appetites for electricity. This difference can be measured as energy between the outside connections. We picture the current flowing in the wire as negative electrons regardless of the

distribution between the positive and negative flow through the solution.

I am not trying to impress you with facts but with the pleasure of speculation about them.

For utility we ought to encourage our instinctive interpretations, even though we know that the pictures cannot endure unaltered. Fortunately we ourselves are sums of different experiences, so picturing natural phenomena is always a new, personal, subconscious integration. The logic may be very extensive, complex, but, fortunately, it is always individually different. Value is measured by works, and individual contributions may either be firm stepping-stones to better things or perhaps only very useful negations.

Guessing, if you will, is not as much encouraged in youth as I wish it were. I myself cramp and cripple my imagination from habit. When we review a subject like electricity, we find that someone has had carefully to make and test all conceivable guesses, good and bad. Someone digressed with his pure imagination far enough to establish new and useful things, like Franklin's lightning-rod, Faraday's electro-magnetic generator, or Marconi's wireless.

In 1889 Professor Trowbridge published his book, "What Is Electricity?" He wrote, "This wonderful something we call electricity circulating around coils of covered wire, makes an iron core a magnet," and, elsewhere in the same book, "Is it not possible, therefore, by enormously increasing the frequency of electrical oscillations, to drive them completely off metallic conductors and compel them to be propagated through the ether of space?" That's wireless.

It is this kind of hesitant divination that I enjoy finding in the minds of men. I think some useful people unconsciously, some intentionally, cultivate it, while satisfied and fearful folk deprecate it.

A sealed letter deposited by Faraday with the British Royal Society over a century ago was recently opened. It was sealed and preserved because Faraday wanted the world finally to know that a new view had come to him first, before there was any way to demonstrate it. Faraday had been led to the view that electromagnetic action progresses through space, and, he says, "requires time for its transmission." He

even added, "I am inclined to think that the vibratory theory will apply to these phenomena as it does to sound, and, most probably, to light." (We still discuss corpuscular and wave theories of light.) It was not until thirty-three years after Faraday secretly recorded his thought that Maxwell showed mathematically that electromagnet waves should propagate with the velocity of light. Twenty-two years later Hertz confirmed this conclusion by his striking experiments and it was still 9 years later (1896) when Marconi made the whole useful. It is interesting to know that Faraday had that particular vision. But it is important to see that Franklin, Faraday, Maxwell and Marconi were all visionary and practical.

While electricity was once purely spiritual and later less mobile though more liquid, it has in our day taken on still more unanticipated forms. Nowadays all chemical elements differ only in the quantity and arrangement of positive and negative electricity. All compounds are slightly rearranged combinations of what the component atoms possess. Only to a slight extent can we add more electricity to a substance than it normally contains and even then the excess slowly leaks away.

In text-books everything is simple. They usually say, "Atoms are collections of a number of electrons and another part called the Nucleus." Or "electrons are little bits of electricity, always negative," and "they each weigh one eighteen hundredth of the H atom." "They are the fundamental and indivisible units of electricity," etc. I subscribe to such views because they keep us going and guessing. They illustrate pragmatism and are as good as true when they become useful.

Imagine the experiments which can be performed when we feel that "the relative ease with which electrons are lost or gained is one of the most characteristic of all chemical properties."

This, we say, explained chemical electricity. Moreover, all material reactions depend upon it. But so does the permanency and composition of everything, even the countless possible new elements which we make now for the first time, new radioactive matter and isotopes. We imagine that an infinite number of different elements were created at the

beginning and all but our 92 mixtures disappeared. They may be replaced. If a few, like radium, attest to the soundness of this view, may we not in some way reproduce or even produce many other elements which will live at least sufficiently long to satisfy some unsuspected future needs? Such speculations, since they lead to experiments, continue a valuable mental process whatever other product results.

The process of leaking electricity, evinced in vacuum tubes, opened a very great field in which radio is now the significant part. The expelling force of heat on electricity introduced the new term "thermionic emission." This, we say, explained that old Edison current between the legs of the filament of his lamp. There are plenty more exact expressions of the thing electricity, than I am trying to give. I need only say that such new terms as "emission," "grid control," etc., become materialized as in radio tubes long before we can explain electricity. Thus our useful vocabulary grows more complex while we seek to simplify the subject.

We think now that everyone knows the electron. It is the indivisible atom of electricity. I hoped it would stay simple. But experts say that it must be regarded as complex, and one adds, "We cannot hope to know what electricity is until much more is learned about the electron's structure." Getting at the internal structure of electrons will doubtless proceed, for we appreciate the growing architecture of atoms and nuclei. It will be interesting, disturbing, and useful. Thus experience teaches: The more we learn about our ignorance, the larger and more useful it becomes. Electricity is less likely to be confined by our limited concepts the more we know about it, but we may always continue to find new uses for it. It was simpler as a spirit, but it is more diffuse as it is.

For the present we adhere to the electron as the simplest and smallest bit of electricity. It was wonderful how orderly orbits of these electrons around an imaginary positive center accounted for all the different kinds of atoms. It was marvelous how shiftings of those rotating electrons accounted for the mysterious lines of visible spectra. Then too into this positive center or nucleus were imagined those significant numbers of electrons which determine atomic numbers and the periodic order of the elements. These electron ideas were all

valuable steps in chemical understanding. Such disclosures open the way to entirely unexpected experiments which in turn help actually to analyze and synthesize new matter. Thus through even wild speculation, good experimental work is forcefully extended.

Even as an all-pervading spirit, one might expect electricity to come out of a spot made too hot for it, but only those familiar with bees in spring, or farmers, could have expected electricity to come out when cold light falls on the hive. Photoelectric cells, whose action is due to electron emission from illuminated chemical elements, are already a commercial utility and speak for the sense and versatility of negative electricity.

Even in this general and superficial talk on electricity, it would seem remiss not to do more with the interesting views now being advanced on the composition of the nucleus of atoms—the heart of matter. At this point all matter was naturally looked at as simply electricity, whatever that is. Fortunately, the process of speculative analysis never has to stop, and such unexpected things as a negative charge firmly neutralized by an equal quantity of positive in a hydrogen nucleus is given the name of neutron.

This naturally followed the studies on the electrons. I cannot possibly reproduce the pictures of the whole interior of the nucleus, but I can indicate the growing complexity of what was recently entirely an imaginary and indescribable center of electron orbits. Its evident electrical nature now forces experimenters into new territory which everyone may later appreciate. The inconceivably tiny nucleus which was first only a positive charge, later became very definite mixtures of positive and negative charges, and then mixtures of protons and neutrons. This once simple nucleus is now becoming more and more complex, but always better understood. It is being shot to pieces through electrical bombardments by alpha particles, protons, deuterons, neutrons, gamma rays, etc. In these processes local electrical voltages up to 20,000,000 or more are being recognized just as we speak of billion volt forces in cosmic rays. Such transcendental potentials might have been visualized before, perhaps in lightning, but if the new views of nuclei did nothing but force us to experiment with

electricity of such high intensities, they would be ultimately warranted.

Cosmic rays ought to be explained before electricity, for in one way cosmic rays are simple. They cause charged electricity to discharge. A metal point, reminding us of Franklin's pointed lightning-rods, is kept electrified to such an extent that it discharges, or leaks, in irregular shots. Many things may perform this trigger action, but when all such known influences were eliminated, there was still an irregular, uncontrollable, shooting out of electricity from the point, and the cause was called the cosmic ray. Experiments above the atmosphere and under earth and water, show that the cosmic ray comes from outer space, and that it penetrates matter very much more readily than it should if it were an electrical monitor of any known kind. Such things keep good research men avid for new ideas. Scientists want to do something about it, and part of the results are always useful as though our engendered wonderment were not warrant enough.

We were taught that action at a distance is impossible. Something in space had to handle the energy. One reads the following about electricity: "The energy in the magnetizing coil disappears from the exciting circuit and reappears in the induction circuit. It must have existed during the time of its disappearance and reappearance, in the intervening space." Such published observations produced the imaginary ether. Still more visionary adepts of science get along without it, and so promising experiments are multiplied.

Having once worked in a chair factory, where belts connected every machine to shafts which were obviously driven by the big belt of a powerful Corliss engine, I naturally still look for belts. I realize that imaginary belts called lines of force are simplifications and have replaced leather in most factories.

But I never cease marvelling at the apparently empty but powerful space between the rotor and stator of electric generators and motors. I realize that all the power is in some way shifted from the remote coils to the busy shaft, and yet I can see nothing in the space. I know that my charged balloons may repel or attract one another, and that this would take place whether the electricity is at rest or moving. We

remain satisfied until we meet some experience not permitted by our picture. It is then that mental wiggling becomes interesting and application becomes valuable.

Confined to post-factual words, our imagination remains cramped and we are slow in inventing new language to cover what we cannot express by previous vocabulary. This is all right, too, because when we invent the new word, we try to express within it the need actually felt for it. By this token, atom, electron, ether, and lines of force have a place in our rapidly changing vocabulary, and represent a great deal of concentrated and promising ignorance. Justification for all this complication is to be found in the resulting works. Attempts to relegate ether to the place where spirits go, lead to fresh imaginings, these to experiments, and those to service.

I do not attempt to envelop completely all electricity and its utilities, but I wonder if one can know what it really is without covering everything connected with it.

A new steel mill, making automobile sheets, now rolls hot ingots continuously into thin strips 8 ft. wide and hundreds of feet long. The maximum delivery speed of the hot mill is about that of a good trotting horse. The mill operates by electricity. Several thousand motors consume the 20,000 kw. of the plant. Both direct and alternating currents are used, and voltages of 2300, 600, 440, and 250 seem necessary. Perhaps a complete definition of electricity would include all this kind of data.

Part of this thing we call electricity might be simple. If there is any simple electrical thing, it must be the permanent magnet. Think how long we have known it! But the picture, view, hypothesis, or essence of magnetism seems as indeterminate as all electricity. The most powerful magnets are now made of a mixture of iron, nickel, aluminum and cobalt, and are much better than steel magnets. I don't see why. We might picture some essence in the property called metallic; but the lodestone, which is no longer metallic but consumed, is also a permanent magnet. So after trying all the hunches on mixtures of metals, anyone might imagine a different and still better magnet made from oxides. One man who felt that way, and was unusually visionary, has produced some first-class new oxide magnets. The important thing is,

he speculated when he learned some facts. Then he tried his experiments. In general, one can safely say about electricity that there never was so much room for new views, and utility, because it never before presented so much of both known and unknown.

You see I am not even trying to explain what electricity is. I'd rather show how rapidly, extensively and intimately it changes, always defying limitations. When it comes to knowing all about it, we have hardly made the start.

One of the earliest electrical investigations was Galvani's research on the nerve of the frog leg, and electrical conduction by nerves has long been an intriguing study. The phenomena are not always simple, but are capable of increased comprehension. The conducting nerve of the frog leg was found to carry electricity by tests similar to those applied to conducting wires, and now the radio receiving test is being applied to brain and nerve energy. The fields for further experiment and useful application are unlimited.

I cannot leave electricity without referring to at least one of its biological implications. Here, too, my idea is to show how little we yet know and how the interesting unknown grows with new views or imagination. In our radio sets a suitable antenna picks up from space electrical influences called waves, which are reinforced, come from the electrical loud speakers as waves of air in imitation of the noises or music actually made at some distant place. This phenomenon is so common that we forget its physical beauty. But in recent biological experiments it has been possible to pick up close to and yet from the human head, electrical waves which are amplified into sounds and recorded as waves on paper. That is the Berger rhythm. This discovery resulted from new views on nervous systems, including the brain, all of which apparently operate electrically. Therefore the motion of electrons of cerebral metabolism may not differ essentially from those of other radio sending stations.

No one can safely predict the outcome of studies in electricity when they involve our bodies, nervous systems and brains. Electricity is, perhaps, like us, various, and yet the sum of all the parts, and certain to be forever growing. The growth will always be due to the inquisitive mixture of imagination and experiment and is in the hands of the young.

THE TREND OF CIVIL ENGINEERING SINCE FRANKLIN.*

BY

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"A man who is less concerned with the golden pavements of the City of God than that the cobblestones on Chestnut Street in Philadelphia should be well and evenly laid, who troubles less to save his soul from burning hereafter than to protect his neighbors' houses by organizing an efficient fire-company, who is less regardful of the light that never was on sea or land than of a new-model street lamp to light the steps of the belated wayfarer—such a man, obviously, does not reveal the full measure of human aspiration. Franklin ended as he began, the child of a century marked by sharp spiritual limitations. What was best in that century he made his own. In his modesty, his willingness to compromise, his open-mindedness, his clear and luminous understanding, his charity —above all, in his desire to subdue the ugly facts of society to some more rational scheme of things—he proved himself a great and useful man, one of the greatest and most useful whom America has produced."

In these words Vernon L. Parrington in his analysis of "The Colonial Mind" described Benjamin Franklin, America's first social philosopher.

To Franklin, the municipal housekeeper, therefore, the present speaker will devote the major part of his remarks, for since the dawn of history the civil engineer has devoted his efforts to directing the great sources of power in nature for the use and convenience of man. His activities have been to a large extent in the field of works of permanent public value. In this field of applied science for the improvement of public welfare, comfort and safety, Franklin was a distinguished pioneer.

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Advocates of mechanical, electrical and chemical engineering will no doubt discover in his activities ample support for their claims that he initiated undertakings in their fields which should result in labelling him a mechanical, electrical or chemical engineer. His facets were many, but in all of his enterprises, the motive of social improvement through scientific works was foremost and in these no small part of his energy was devoted to the civil engineering field. Most of his activities fit into a general plan, although they range from the founding of the first public library in 1732, the institution of plans in 1743, which ultimately resulted in the present University of Pennsylvania, the writings which bore fruit in the establishment of a Pennsylvania Militia, the program for the development in Philadelphia of paved streets, street lighting and improved police and fire protection and his interest in agriculture, the land problem, the organization of the colonies and the expansion of the colonial frontier.

Even in founding the Philosophical Society he pointed out that its energy should not be devoted solely to abstractions, but to the spread of new discoveries and useful knowledge in practical affairs.

What kind of world was the United States in Franklin's day? One hundred and fifty years ago the inhabited part of the United States consisted principally of the area east of the Allegheny Mountains and between the St. Lawrence River and the Spanish Province of Florida. The first census of 1790 of the New Republic showed a population slightly less than 4 million. The living conditions of the great mass of the people was simple, with open fires or brick ovens, lighting with tallow candles or the sperm oil lamp, clothing of homespun, few public water supplies, no public sewerage systems, plumbing practically unknown, with primitive methods for the removal and disposal of household and industrial wastes.

At the time of this first census only four municipalities in the United States had populations in excess of 10,000—New York was a metropolis of 33,131; Philadelphia of 28,522; Boston, 18,320 and Baltimore 13,503. The remaining population lived under rural or semi-rural conditions.

In the intervening 150 years this meager society of men grew to 130,000,000 souls. To make this possible an un-

precedented extension and utilization of science and engineering to ameliorate and control the environment of man was an absolute necessity. In that extension Benjamin Franklin pointed the way. The Philadelphia of his day was small, filthy, unprotected against fire, against thievery and against disease. The streets were muddy, frequently impassable, dark and dangerous. An Englishman visiting the city in the 1790's described its harbor as putrid and dangerous to health.

Water Street, in 1793, was the hub of the spread of yellow fever throughout the City. In the yellow fever epidemic of the summer of 1793, "the poor of the congested quarters near the water front fell like flies in the winter. Soon it spread to the best residential sections. Soon all the great houses were closed, and everyone who could afford it, abandoned his business and fled from the stricken city.—Day and night the death carts rumbled through the town.—The streets were as those of a dead city.—Life-long friends evaded one another like guilty creatures. Even the families of the stricken fled, leaving the suffering to die in barbarous neglect.—Only the negroes seemed immune and much to their honor they zealously contributed all in their power . . . .

"When the death toll mounted from scores to hundreds, from hundreds to thousands, the neighboring villages and towns met to devise plans for keeping the Philadelphians away. . . . The death rate increased frightfully. It was impossible to keep a record. On October 20, Wolcott wrote Washington that more than 4000 persons had died."

With the approach of winter the disease died out having taken a toll of almost one-sixth of the total population of Philadelphia. This attack of yellow fever was typical of the impact of disease upon most of the cities of the United States of that day. Their number and their kind, multiplied ten fold, dominated the program of the succeeding century and a half, a program directed primarily to the conquest of the material environment of our people.

Restrictions of time alone make it impossible to multiply the descriptions of American communities of Franklin's day. They were universally characterized, however, by the absence of public interest in or control of the deficiencies or dangers of environment and by the inadequacies of private and public

funds for protecting and safeguarding the lives of citizens. Franklin's insistence upon extending public responsibility for streets, for public lighting, for police and fire protection marked the first recognition in this country of the responsibilities which growing populations place upon the civil engineer and simultaneously upon organized society at large. He was the first to emphasize that the people walked this earth upon a thin crust of civilization.

It is peculiarly appropriate, therefore, for a member of the civil engineering profession to review the progress in that field since the day of Franklin. A detailed statistical summary of the advance in the various fields of civil engineering during 150 years would be possible, but no doubt appalling to any audience. The speaker will select from that history, therefore, only three or four phases of civil engineering in which the progress has paralleled that of other sub-divisions. Again only the significant trends in these limited fields and their import to society will be discussed.

ROADS.

If Franklin were to return to this earth in 1938, perhaps the most impressive physical change in his favorite American city would be in the highways and streets. He himself described Philadelphia of his day as "filthy-dirty," because of the unpaved streets, the quagmires in winter and the stifling stretches of dust in summer. With true, but rare, municipal conscience, he introduced the first bill in the legislative assembly of Pennsylvania providing for paving the entire city and establishing, incidentally, for the first time, public financial responsibility through the assessment method.

An exposition of the development of the highway since that time would require a volume in itself, if ample discussion and speculation on the effect of highway development in shaping America's destiny as a nation were to be considered. For our purposes, it is important to point out one impressive change which that development has brought in its wake, namely, the tremendous reduction in time and space relationships over that of a century and a half ago. Even our form of government, as originally established, may have been some-

what regulated by the inadequate facilities of communication between the colonies.

When Washington came from New York to Annapolis to attend the ball in his honor after the Peace, the trip required 13 days, a distance which may now be covered in less than one-third of one day. In that same period it took a day of almost 24 hours to ride from Elkridge Landing in Maryland to Annapolis, a distance of less than 30 miles.

From 1743 to 1775, additional highways were opened to the west. In 1775 Daniel Boone marked out the wilderness road through the Cumberland gap to Kentucky. The location of the road was a monument to the skill of Boone as a civil engineer and surveyor, for he laid out 200 miles of road through a mountain wilderness which, for a hundred years, remained practically unchanged. These developments were followed in the 1780's by the construction of many turnpikes operated for the most part by turnpike companies, many of which continued in operation for 100 years thereafter.

The construction of the National Pike was initiated by an Act of Congress in 1802 and in 1805 the building of the road from Cumberland, Md., to the Ohio River was authorized. The first contract for its construction was let on April 11, 1811, and the road was completed from Cumberland to Wheeling, W. Va., about ten years later. The total length of this section was 131 miles and the total cost of construction was $1,706,845 or an average of $13,029 per mile. Today it would probably cost us $10,000,000.

This period was followed by an epidemic of plank road construction begun in Syracuse, New York, about 1846. Within 4 years more than 2,000 miles had been constructed in New York State alone. By the third quarter of the 19th century modern types of pavement were introduced in this country, with brick pavements in Charleston, W. Va., in 1872, sheet asphalt surface on Pennsylvania Avenue in Washington in 1879 and rock asphalt surface in Newark, New Jersey, in 1870.

To New Jersey belongs the credit for the first practical step taken anywhere in the United States, in 1891, to participate directly in the construction of roads, although Kentucky for many years prior thereto had established a well defined

State road policy with a State Highway Department from 1821 to 1837.

After a lapse of almost 55 years the Federal Government assumed once more participation in the highway program of the country by an Act of Congress in 1893 establishing a Department of Road Inquiry. Up to 1904 there had been no important change in the methods of road construction that had been used for a century or more. In 1904 the United States Office of Public Roads, the successor to the United States Department of Road Inquiry, took the first census of American roads. In that year there were 2,151,570 miles of rural highways, of which 153,662 miles had been surfaced with various materials.

The decade following 1904 was marked not only by the development of new types of road, but by two other changes of much greater significance. A general increase in the radius of travel by highway was occasioned by the use of the automobile and secondly, a complete change occurred in the character of the public demand for highway improvement. These major changes in turn resulted in the initiation and extension of Federal aid through a series of Federal aid road acts, with accompanying grants-in-aid by the Federal Government of increasing total amounts since 1916.

At the end of 1924, over three million miles of highways had been constructed in the United States, of which somewhat over seven hundred thousand miles had been improved in some degree.

In the State of Pennsylvania alone the total surfaced and improved roads in 1937 amounted to 27,935 miles. The unimproved roads totalled 10,099 miles and approximately 46,500 miles of second class township roads of lesser importance. This is a far cry from the first struggle which Franklin had to obtain a legislative act for the paving of the streets of Philadelphia. During the period from 1917 to 1938 inclusive, the Federal aid grants to Pennsylvania alone totalled approximately $139,000,000.

It is of passing interest, however, to remind Pennsylvanians that history repeats itself, for in 1937, its Legislative Assembly reverted for one reason or another, to the turnpike days of 1785 by the passage of an act creating the Pennsyl-

vania Turnpike Commission, with authority to construct and finance a turnpike from Middlesex, Cumberland County, to Irwin, Westmoreland County. The construction is to be financed wholly from funds derived from bonds to be issued by the Commission, and these bonds will be secured solely from revenues from the turnpike. The officials of the Lancaster Turnpike Company incorporated by the Governor on April 9, 1792, may well turn over in their graves.

In 1938, the Federal aid contribution to highway construction will probably exceed $238,000,000, indicating a 1938 highway program in the United States exceeding $1,000,000,000. When Cyrus, the Elder, during his reign in the Persian Empire, constructed roads in 559 B.C., he opened the way for that continuing demand for trade relations between the people of a country. Franklin extended that program at the end of the eighteenth century and the end is not yet in sight.

WATER SUPPLY.

At the close of 1800 there were only 17 waterworks in the United States. All but one of these was privately owned. For the most part the water works of the colonies were simple, with most of the community works consisting of large wells from which the householders carried water. New York, Philadelphia and Boston had water supply systems prior to 1800, but they were inadequate for either domestic or public purposes. As a matter of fact, a water works owned by Aaron Burr's Manhattan Company, created under an act of the legislature in 1799 for New York City, consisted of a large well and two pumps. Since the real object of the company apparently was to conduct a bank under a clause concealed in its water company charter, it made no strenuous effort to furnish water for general municipal purposes.

By 1832 the supply furnished in the City of New York by the Manhattan Company and by the public and private wells was so offensive that all who could do so purchased water from unpolluted wells in the northern part of the island. The water was sold for $1.25 a barrel. With a serious outbreak of cholera in 1832, discussion for a more permanent and safe water supply crystallized in an election in 1835 when the Croton project was approved by the citizens. Croton water

was delivered to the city in 1842, when the city had attained a population of more than 300,000.

After the great fires in Chicago and Boston, the number of water plants in the United States increased from 243 in 1870 to 598 in 1880. By 1900 this number had increased to over 3,000 and today there are well in excess of 10,000 public water works in the United States supplying over 80,000,000 people. While in 1800 the percentage of water works owned by private companies exceeded 90, the reverse is probably the case at this time, showing a continuing trend toward public assumption of responsibility for supplying safe and adequate water supply to the people.

Important technical changes in the materials and equipment for water works systems naturally paralleled the development in extension and ownership of these facilities. The change from bored logs in the early 18th century to cast-iron pipe, first laid in Philadelphia in 1807, marked the first important improvement in materials in distributing systems. Wrought iron pipe appeared in the 1840's as a competitor and with the advent of hydraulic mining in California in the 1850's, wrought iron and steel came into wider use because cast-iron was too expensive in the western territory. It was in this fashion that wrought iron and steel water pipe gained a foothold on the Pacific Coast for distribution systems from which they have never been dislodged.

The first important riveted wrought iron water pipe in the east was laid in Rochester in 1875. Into this active competition between materials, reinforced concrete pipe later entered, so that today we have an ever increasing variety of materials for this important part of our public necessities.

The construction of dams and reservoirs has increased in numbers and in complexity, with a variety of structures available for every purpose under the sun. The theoretical bases and the practical controls have been steadily amplified for hydraulic fill dams, for rock fill dams, for arched dams, hollow dams, steel dams, with increasing volumes, heights and strengths, culminating in such structural wonders of the engineering world as the Boulder and Grand Coulee Dams.

It is particularly appropriate to point out that Pennsylvania not only holds the record for the first water supply, but

also for the first public supply furnished by pumping. The pump was installed for the City of Bethlehem in 1754.

The first steam pumping plant in Pennsylvania was put in operation in 1801 in Philadelphia on the Schuylkill River at the foot of Chestnut Street. The steam pump held practical sway over the water pumping field from 1800 until about 1900 when the centrifugal pump became a strong competitor for favor.

Paralleling these changes in pumping were the equally important changes in the improvement of the quality of public water supplies by the introduction of filters in the early 1870's for Poughkeepsie and Hudson, New York. Although such filters had been constructed in London as early as 1829, their application in this country did not begin until the early 1870's. It is difficult for most of us to realize the extent to which the United States suffered from the scourge of sewage polluted waters, which caused epidemics and almost continuous typhoid fever in most cities. These scourges were particularly severe in the manufacturing cities of Massachusetts and in the steel districts of western Pennsylvania. Most of us have forgotten that a number of visiting engineers at the Columbian Exposition at Chicago in 1893 contracted typhoid fever while there.

In 1892, Asiatic Cholera appeared on vessels quarantined in New York harbor and in 1895 detailed investigations began in Louisville on rapid or mechanical filtration.

The first reinforced concrete units for filters were adopted at Little Falls, N. J., in 1901. By 1938, filtered water was being supplied to over 30,000,000 people with a daily capacity exceeding approximately 5,000,000,000 gallons. In the interval of approximately 150 years, the typhoid fever death rate per 100,000 population has declined in this country from approximately 75 to less than 2. If the death rate of 1800 prevailed today for this disease, 13,000 more people would have died in the United States in 1937 than did. In Philadelphia, the death rate for this same disease per 100,000 population varied from 60 to 78 in the period from 1880 to 1890 while in Pittsburgh, for this same decade, the rate climbed as high as 158 per 100,000. In both cities, fortunately, this disease has dropped to a death rate of less than 2

in 1937. In the field of water supply improvement, progress in applied science has far outstripped even the highly imaginative hopes of a Franklin. Many of the devices were still unknown to him and certainly their widespread availability was hardly to be anticipated.

The effects of epidemics in the early days of the Republic on pushing forward installation of public water supply and sewerage facilities can hardly be overestimated. Yellow fever and cholera between them created havoc decade after decade with important results so far as municipal housekeeping was concerned. In New York City, yellow fever epidemics occurred in 1791, 1795, 1798, 1799, 1805, 1819 and 1822. The epidemic of 1798, when the population of that City was only about 80,000, resulted in more than 2,000 deaths. In the southern cities, of course, yellow fever persisted until almost the 20th century.

It was extremely fortunate, however, that the "building out" of yellow fever in the United States did not have to wait upon the discovery of the part which the mosquito played in the transmission of that disease. The increasing public demand for sewering and draining cities to avoid nuisance and to gain convenience diminished remarkably the incidence of yellow fever, due primarily to the elimination of the breeding places for mosquitoes. In similar fashion the epidemics of cholera in 1832, 34, 49, 54, 66 and 73 brought about a certain amount of recognition of the probable relationship between this disease and the inadequate and unsafe methods of the disposal of household wastes, and undoubtedly stimulated the establishment of drainage and sewerage systems in the larger communities.

SEWERAGE.

Perhaps the first application of engineering skill to the design of sewers was for Brooklyn, New York, in 1857, followed by similar developments for Chicago, Ill., in 1858. Some 15 years later installations were designed for Providence, R. I., and Boston, Mass. The first systems of separate sewers in America were built in 1880 at Memphis, Tennessee, and at Pullman, Illinois. After three-quarters of a century no

large municipality remains in this country without a water-carriage sewerage system.

The progress in sewage treatment and the consequent correction of resulting stream pollution has not been as favorable. Much remains to be done in this last step of handling the sewerage problems of metropolitan areas by adequate control of the discharge of raw sewage, although at this time the sewage from more than half the total urban population of the United States is subjected to some form of treatment. One of the important problems still demanding more adequate solution deals with the discharge of untreated industrial wastes. Industry by and large is one of the principal offenders in the pollution of our streams, either through difficulties in finding technical methods of treatment or through inertia or through lack of funds. The problem offers one of the pressing challenges in modern stream control.

In 1875, of the 67 cities having a population of 100,000 or more, according to the 1920 census, not one was treating its wastes. By 1900 only two of these same cities had built treatment plants for approximately an aggregate population of 197,000. Today 37,000,000 of a total population supplied with sewers of 72,000,000 have made provision for sewage treatment.

REFUSE DISPOSAL.

Progress in the collection and disposal of refuse has followed that in the fields of water supply and sewerage. As early as May, 1701, discussion of public procedures and of public payment for cleaning the streets was under way, but it was not until the third quarter of the 19th century that any real progress in this additional phase of municipal work was made. In statistics on about 70 cities in the United States in 1876, only 25 were removing house refuse in carts. In the remaining 45 places it was either thrown into adjacent cesspools, fed to hogs, thrown into the nearest river, dumped in nearby valleys or used for fertilizer. In less than half of these cities was there anything approaching a regular collection service. For the most part the refuse was frequently dumped on the streets, from which it was gradually removed by hogs, scavengers or disintegration by traffic. Special methods of disposal began late in the 19th century. Today refuse

collection and disposal is provided by virtually every large municipality in this country. Considerable room for improvement and extension of facilities remains, but the last century and a half has provided a record of increasing efficiency and availability of processes and equipments. Future progress will depend upon the character and training provided in municipal governments.

GENERAL PROGRESS IN CIVIL ENGINEERING.

The examples presented may be multiplied in virtually all the fields of civil engineering practice. Adequate review and discussion of the advances in waterways engineering, in the design and construction of bridges and tunnels, in the development of power, in the vast programs of river regulation for flood control and reclamation, in railway transportation, in building construction, in the science and art of ventilation and in many other branches, would require volumes. They all tell the same story of major use and application of the fruits of science, by orderly processes, to the service and benefit of men. The beginnings of civil engineering certainly date back at least as far as 3000 B.C., but in number, complexity and wide spread application the works of civil engineers have shown their greatest advance since 1750. Perhaps the most significant phase of that advance is in the recognition by Franklin and his successors of the major responsibility which rests upon government for the continued extension of engineering works for the benefit of society in general. It was only after the middle of the 18th century that the profession of engineering began to receive public recognition. As a matter of fact, it was just after 1750 that John Smeaton, James Watt and Henry Cort, all contemporaries of George Washington and George III, began true engineering experimentation and led the way to the solution of problems in engineering on a scientific rather than upon an empirical basis.

There then followed the great eras in the United States of bridge building, of canal building and of railroad extension. The development of steel in the middle of the 19th century, followed by pioneer tunnelling methods and the universal application of nitro-glycerin, added to the equipment of the civil engineer. Throughout this whole period of a century

and a half, structures of every sort were pushed forward with increasing research, with new tools and with ever increasing use of public funds.

Some index to this remarkable growth of civil engineering works is afforded, of course, by the increase in numbers of individuals associated professionally with these activities. The American Society of Civil Engineers had a membership at the time of its founding in 1852 of less than 100. By 1936 its membership had exceeded 15,500, a figure which, of course, does not include by any means all of the professional civil engineers of the United States. The trend of membership increase, however, again parallels the increased demand in this field of activity.

RETROSPECT AND PROSPECT.

Since the days of Benjamin Franklin time-space relations have changed, population has multiplied almost fifty fold, the area of the country has been almost tripled and the fruits of science have been generously applied for the benefits of man. It is a far cry from the engineering day of the land surveyor with "the nice combination of technical skill, and woodsman's instinct," who combined the functions of surveyor, historian, arbitrator and magistrate, to the skillful mathematician with tools of precision, the civil engineer of today.

How far Franklin's interest in the problems of the atmosphere, in his experiments with balloons and kites, and in ventilation, has been extended in daily application would have both intrigued and astounded that inquisitive philosopher. This one field of the ordinary "bookkeeping" of society exemplifies the profound changes from the past. It is interesting to speculate upon what his reactions would have been to the development of meteorological observation stations over this entire country and extending to Alaska, the West Indies, Canada and Mexico, with first steps taken for even international exchange of reports for similar stations throughout the world. He was so greatly interested in all matters of weather on every one of his ocean trips that he no doubt would have been pleased with the meteorological reports from ships at sea by the use of radio, one of the most important developments in the entire history of our Weather

Service. One can imagine the excitement which would have been aroused at a meeting of the Junta on reporting on the use of the radio-meteorograph, an instrument attached to a balloon which sends back signals of pressure, temperature and humidity from the upper air at heights well above those attainable by aeroplanes.

It is perhaps fitting that in the Commonwealth of Pennsylvania the first widespread service for river forecasting should have been established in 1937, with the location of 130 recording rainfall stations on the watersheds of the Allegheny, Monongahela, Susquehanna and Delaware Rivers. The developments in this particular field are mentioned not only because they were so close to the heart and mind of Franklin, but more important because they are excellent examples of an increasing complexity of a universe which demands from science applications which make for safety, health and comfort of society.

The primary interest of Franklin in public service makes it important to emphasize and reëmphasize that in our pride in the performances of the past 150 years we should find increasing challenges for the future. It is unfortunately true that the accomplishments of the past so frequently create both the complexities and the opportunities of the future. This is particularly true in the field of which we speak today, because parallel with the engineering developments herein broadly delineated, has evolved the social and economic life of the nation. By virtue of this parallel growth it is true for the American as for the average English citizen, as Graham Wallas has recently pointed out, that the "possibility of health, of happiness, of progress, towards the old Greek ideal of 'beautiful goodness' depends on his local government more than on any other factor in his environment." So smoothly has this system worked in its essentials since the day of Franklin and since his inspiration to its creation, and so accustomed are we to its existence, that we not only overlook the vast amount of activity which led to its creation, but we may ignore the problems involved in the efficient maintenance and extension of its benefits.

The recognition by Franklin that government has responsibilities for applying the fruits of science to the needs of

man marks him as perhaps one of the most important civil engineers of his day. He was one of the first master planners of our country, performing the most useful function of the engineer as the guardian of nature's resources. That he builded well in his introduction of government into the affairs of men can no longer be doubted, for since his day government has virtually halved the death rate and reduced the infant mortality rate by three-quarters. It has relegated cholera, smallpox and enteric fever to the archives of history. It has reduced tuberculosis to proportions regarded a century ago as impossible. In similar fashion, comfort and convenience of the people, not so easily statistically demonstrable, have enormously increased as other related services have moved forward.

This discussion, however, should not be closed upon the note of celebration of the triumphs of the past, without reflecting upon the emerging needs of the future. The progress in engineering during the past century and a half brings into sharp focus some of the probable difficulties of the future. Perhaps the first and most pressing of these lies in the structure of our local and central governmental systems. Civil engineering activities of the last quarter of a century have become increasingly dependent upon and intimately related to the operations of government. It is unlikely that the next 25 years will see any relaxation of this relationship. If progress in civil engineering is to continue it must carry with it improvements in governmental functioning, particularly in the structure of local government. This is especially true in that vast field of engineering enterprise dealing with the control, development and regulation of the water resources of the country. As these problems impinge upon associated problems of land, minerals and industrial development, it becomes apparent that the present areas of local government operation will require moving integration with the higher levels of government.

A vast expansion in scale and scope is probable in the fields of public health, education and housing, in two of which at least, civil engineering is likely to play a significant part. In the century and a half which has passed, the energies of authorities have been directed primarily to the conquest of

the material environment, which some authors have perhaps too aptly described as a municipal administration with a "pedestrian and unimaginative flavor." Perhaps the future may demand an extension of the municipal horizon to the cultural aspects of civic life.

All of this will demand an increase in size and in professional quality of the engineering expert to whom new responsibilities and new leaderships will be entrusted, for in spite of all of our fears government will continue to assume new responsibilities and with it civil engineering must proceed. The future holds new hopes for a new kind of pioneer. A new frontier, technological rather than geographical, remains to be crossed with the same courage and with the same promise as Franklin foretold that "perhaps in less than another century the Ohio Valley might become a populous and powerful dominion." In the same vein the civil engineer of today views the next hundred years of his country as a territory virgin and rich in its promise of new returns to our people. He must continue Franklin's task of "subduing the ugly facts of society to some more rational scheme of things."

ENGINEERING AND HEALTH.*

BY

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Health is one of the most precious of human possessions, and serious illness one of life's most heartrending trials. It is not so much one's own ailments that are heartrending—many people bear pain and incapacitation with astounding fortitude and even cheerfulness—but to see a loved one fighting pneumonia or infantile paralysis, crippled by arthritis, wracked by the agony of a heart attack, or bravely enduring the slow gnawing of cancer, and be powerless to do more than stand by and wait, is almost the most distressing of human experiences. Even when there is every hope of ultimate recovery it is hard to be patient; the restless urge to be doing something is almost overwhelming.

Perhaps it is for this reason that generous-minded men and women are so easily persuaded to make liberal gifts to hospitals, to medical schools, and to institutes for medical research. Doubtless it was this sort of keen sympathy for human suffering that led Benjamin Franklin to promote, in 1751, the founding of the Pennsylvania Hospital, to write on lead poisoning, to conjecture as to "the cause of the heat of the blood in health, and of the cold and hot fits of some fevers," to be concerned about "what is called catching cold," about a cure for cancer, and about inoculation for smallpox, to have, in short, such varied interests in the field of medicine as to be elected to membership in the Royal Medical Society of Paris, and in the Medical Society of London.

But Franklin was a many sided man, and we also find him inventing lightning rods, promoting the paving and better cleaning of city streets, discussing the draft in chimneys and the construction of smokeless fireplaces, inventing the Franklin stove or "Pennsylvanian fireplace," and, forty years later,

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describing "a new stove for burning pit coal, and consuming all its smoke," a series of activities that would now be called engineering. May they not, perhaps, have had as potent an influence in promoting the health and physical well-being of his contemporaries as did his hospital?

To modernize the question, to what extent can the engineer be thought of as rivaling the physician in the promotion of health? In appraising this friendly competition, let us not forget that while the engineer's achievements are never so dramatic, spectacular, or individualized as is the saving of a life or the restoration of a sufferer to vigorous effectiveness, the engineer deals, not with individuals, as do most physicians, but with the great masses of men, women and children that constitute modern communities. If, then, the intensity factor of his health work is, perhaps, less than that of the physician, its quantity factor is, in general, immeasurably greater. Many more people have used one of Franklin's Pennsylvania fireplaces than ever went to his hospital. And since any appraisal of the effectiveness of any sort of work, in physics or in life, depends on the magnitude of a product containing both an intensity and a quantity factor, and since the intensity factors of the various engineering activities that promote health will, I believe, be found to be far greater than that zero which alone could nullify the significant product, it is, perhaps, not unreasonable to suggest that the engineers of today are contributing quite as much to the promotion of health as are the physicians. I say this without any thought of minimizing the magnificent achievements of the medical profession, but merely in the hope that the mention of some commonly overlooked aspects of the work of engineers may bring to them an even greater measure of public understanding and appreciation than they now enjoy.

The virtue of Franklin's lightning rod is that it prevents disaster. A similar service is rendered by modern flood control methods which often involve engineering works of tremendous magnitude, by the light-house service, by the ice patrol in the North-Atlantic, by the use of radio on ships at sea, by the intricate interlocking switches, signals, and automatic train-control systems on railroads, by the air-beacons, lighted fields, radio beams, blind flying instruments,

and radio telephones of modern transport flying, and by all the devices and slogans that are making the work of the modern safety engineer so surprisingly effective. If a penny saved is a penny earned, so too is a disabling accident avoided the equivalent of a medical triumph.

Engineers have also done much to help the physician do his work by developing and fabricating for him many useful and even indispensable instruments, such as the X-ray machine, the electro-cardiograph, many devices for electrical and thermal therapy, many intricate optical instruments from the microscope to the cystoscope, and all the devices that make a modern operating room, and even a modern doctor's office, such a striking example of twentieth century mechanization. Furthermore, the radio of the engineer has brought to many a disabled seaman medical diagnosis and directions for treatment that formerly would have been wholly unavailable. The contribution to the effectiveness of health services, the world over, made by the daily broadcasts directed by the Singapore Bureau of the League of Nations is very great. The radium of the physician is extracted from its ore by engineers. In all these ways engineers are helping doctors to do their work more effectively, and thus contributing to the maintenance and promotion of health.

The most obvious, because the most direct, contributions of engineers to the promotion of health lie, of course, in the field of sanitation. By bringing abundant supplies of pure water into towns and cities, a boon that only those who have lived or traveled in arid regions can fully appreciate, by building sewers and sewage disposal plants, by modern methods of refuse-collection and disposal, by the invention and fabrication of modern plumbing fixtures, which make cleanliness easy, and by carrying forward the work that Franklin initiated on the elimination of smoke, engineers have undoubtedly saved many lives and relieved the world of much suffering. And while the medical men have had to lead the way in attacking such diseases as hook-worm, malaria, and yellow fever, it has been the sanitary work of engineers that has put this hard-won knowledge into practical effect on a large scale over considerable areas. Indeed in the whole field of public health work and of preventive medicine in which so

many forward looking physicians are actively engaged, engineers are their indispensable allies. The tremendous influence which these various sanitary and other advances have had on the general health level of the population as compared with what prevailed in Franklin's time is too striking for further comment.

In the important matter of diet also, the work of the engineer has been of importance. By the development of tinplate and of intricate machines for fashioning it, he has made possible the canning of food on a tremendous scale, thus broadening and enriching the diet of the nation, and making available at all seasons, and in the most out of the way places, foods rich in vitamins and hormones. The development by engineers of refrigeration on ships, on trains, in cold storage warehouses, and in the home, including the newest methods of quick freezing, has contributed to the same end. Irrigation, often involving engineering projects of enormous magnitude, has helped the farmer to produce food in greater abundance and often of finer quality. Still more fundamentally, the ships and trains themselves, and the motor-trucks, all invented, developed, and fabricated by engineers, are the means by which most of the food of the nation is brought to those who consume it. Without them no modern urban population could exist. By these means engineers have profoundly affected the dietary habits of whole nations and have made possible the elimination of deficiency diseases and of the lowered resistance to infection that malnutrition causes.

In the matter of housing, also, engineers have played their part. They have improved the materials and methods of construction, and therefore both the availability and the usefulness of buildings of every sort. They have flooded houses, offices, and work shops with eye-saving light. They have transformed Franklin's Pennsylvania fireplace into a central heating plant that provides a uniform controllable temperature throughout a house. Air conditioning is just around the corner. And by developing transportation they have enabled an urban population to find over a far flung area more healthful living conditions than were available even to the well-to-do of, let us say, the London that Franklin went to in 1757.

In all these ways engineers have contributed directly to the maintenance and improvement of the health of vast numbers of people. This is, however, by no means the whole story. There are certain other activities of engineers that are, perhaps, not so commonly recognized as having a bearing on the health-level of a nation.

Consider, first, all that is involved in what is called a national standard of living. Technical achievements in sanitation, in the production, transportation, and preservation of food, and in housing may determine what is available to those who can afford to have what they want; but it is the national standard of living that determines what the average man actually gets. If the national standard of living is low, there will be bad housing, bad sanitation, mal-nutrition, a prevalence of deficiency diseases, and a general lowering of resistance to infection and of recuperative power that will be responsible for much sickness and many deaths. By far the most effective way of raising the general health level of any population is to raise its standard of living. This problem is, fundamentally, not medical but economic.

But the standard of living of a community is nothing else than its production of goods and services per capita per year. Unfortunately this is not always the same as a community's capacity to produce per capita per year. At the moment, for instance, we apparently do not know how to make our economic system function in such a way as to permit men to make and consume all they could easily make and would like to consume.

But in the long run the actual production of a community per capita per year will be determined by its capacity to produce, and its capacity to produce will be conditioned largely by the possible production per man-hour of expended labor. In other words, in the long run, the only way to raise the standard of living of any community, and with it the general level of the health of that community, is to increase what a man can do in an hour by giving him more inanimate slaves in the form of horse-power and kilowatts, by giving him more and better tools and machines to work with, by mechanizing and automatizing more of the routine operations in his productive processes, by working out technological advances

and inventions that displace some useful thing that is hard to make by something else equally useful and easier to make, by showing him how to handle things more deftly and how to postpone or avoid fatigue, and by more effectively organizing the team-work of the industrial unit in which he works. Only by such means as these can the standard of living of any community be permanently raised. And only engineers can provide these elements in the increased hourly productivity of the workman of today and tomorrow. By raising our scale of living in the future, as they have marvelously raised it in the past, engineers can markedly affect the future health-level of the whole population.

Over shorter periods, a high standard of living is characteristic of what we call prosperity. Anyone who ventures to talk about the business cycle is treading on dangerous ground. But it is, I think, generally admitted that a characteristic of most waves of prosperity is the rise of an important new industry. The automobile and the radio are striking examples. What the next new industry will be, no one knows. But it is surely safe to assert that, when it comes, engineers will have been responsible for its genesis and growth. Only industrial activity, energized by the genius of the engineer, can generate good times. If then, it is to engineers that we must look both for the long term trend, and for the cyclic bulges, in the upward progress of our standard of living, their part in the maintenance and improvement of the health of the nation is great indeed.

All that I have said thus far pertains to the *physical* health and well being of mankind. But our friends the physicians know even better than the rest of us the importance of that other aspect of men's lives that may be called *mental* health. Always important in itself, it often influences, if it does not completely dominate, physical condition.

Here particularly we can look to him whom we honor today for an almost perfect example of this important human quality. Franklin was indeed, to quote Mr. Julian P. Boyd, "a man unacquainted with inhibitions and repressions and spiritual malaise"; "he accepted the world as given with imperturbable serenity"; he "took it all easily, relishing it, savoring it, without rest and without haste adding to his

knowledge, fortifying and tempering his intelligence, broadening his point of view, humanizing and mellowing his tolerant acceptance of men and things." I know of no better description of mental health. Nor do I know of any better prescription for living happily, as Franklin did, to the age of eighty-four years.

But how, you may well ask, can engineers contribute to the widespread diffusion of such mental health as this? It is, of course, too much to hope that large numbers can ever be brought to anything like the perfection of sanity, poise, and serenity of Benjamin Franklin; but to bring any considerable number of men and women even a little nearer to perfect mental health would be an important achievement. This I think engineers can help to accomplish in at least two ways.

The first depends on the fact that a considerable proportion of men and women spend more than a third of their waking hours on an industrial job of some sort. Someone has said that the chief difference between a professional man and a job holder is that the former lives through his work, the latter by means of it. I see no reason why this cynical characterization of industrial work should be accepted as inescapably true, or why such work cannot be made to afford to the worker an acceptable and satisfying way of living. The old fashioned craftsman thoroughly enjoyed his work—at least many modern writers seem to think he did. And I believe that many of today's workers enjoy the part they play in industry. We are all too likely to ignore all the non-financial incentives and rewards of business and industry.

But enjoying one's work is greatly enhanced by, if it is not actually dependent on, having a job that one can do well. This is where the engineers come in. They are beginning to feel their way into new fields of management which involve both adjusting jobs to their holders and assigning men to the right jobs.

Adjusting a job to its holder may be done by a machine designer or by a motion-study specialist. Many modern machines are designed with special reference to the convenience and comfort of those who are to operate them; though how much remains to be done is indicated by the saying of one of my friends that there is only one machine in

the world that is perfectly adapted to the operator, and it took three thousand years to do that—the machine in question being the axe-handle. And to the extent that motion-study is used to make jobs easier and less fatiguing, rather than merely to speed up production, it can confer great benefits on the worker.

Assigning men and women to the right jobs holds even greater promise of materially raising the general level of mental health of the working population. Industrial managers are beginning to make notable progress in studying human beings objectively, in measuring individual differences, in appraising both the strengths and the weaknesses of prospective employees, in cataloging the pattern of strengths and weaknesses most appropriate to each particular job, and in assigning men and women to the right jobs. I could tell you, if time permitted, of men who came into an industrial testing laboratory restless and inefficient, sometimes even morose and uncoöperative, because they had strong aptitudes of certain kinds on which their jobs made no demands whatever, and how, in many cases, reassignment of these men to jobs that called into play all their aptitudes resulted within a year in almost miraculous alterations in personality and outlook on life. I could tell you of women, trained at their own request as comptometer operators, who became nervous wrecks within a year because of the lack of a certain necessary aptitude which could easily have been detected in advance. Nor should we forget the intangible but often important stimulation to personality that comes from the mere fact that one has been studied and measured, that one's abilities have been sought out and recognized, that one's life has been paid attention to and discussed as an individual adventure. Not that the millennium is immediately at hand by any means—the engineer-managers of today have only just begun to scratch the surface of this highly promising field—and he who tries to go too fast in it will come a cropper, and perhaps temporarily discredit the whole field. Nevertheless I am convinced that this kind of activity will produce, in the next twenty-five years, a greater harvest of human satisfaction and mental health than any of us can yet conceive of.

Turning now to the second way in which engineers can hope to help bring more abundant mental health to the world, we find ourselves facing a much more difficult problem. Perhaps I am over-optimistic in even mentioning it as one that engineers or anyone else can hope to solve. And yet, in its various ramifications, it is probably the most important problem that civilization faces today. I refer to the problem of industrial instability, the problem of the recurrent recessions and depressions that periodically throw millions out of work and disrupt, sometimes permanently, the lives of many of them, the problem of social insecurity.

That social insecurity can profoundly affect the mental, and even the physical health of great numbers of people, is indubitable. Worry has wrecked more lives than tuberculosis has. And there is no worry so insistent as that which besets a self-respecting industrial worker, and his whole family, if he thinks there is danger of losing his job, except that of the worker who has lost his job. I suspect that this sort of worry is by far the most important single factor in the American health situation today.

What hope is there of lightening this incubus of fear caused by industrial insecurity? What hope is there of steady, perhaps even of guaranteed employment?

Two types of thinking are current with respect to problems of this sort, one political, in the best sense of that word, the other industrial. It is characteristic of the political type of thinking, whenever a social problem can be defined at all, to attempt to solve it by enacting a law. This type of thinking holds, consciously or instinctively, that social progress can best be forced forward by legislation. This dogma, to those who are persuaded of its validity, is comforting. It affords them an opportunity to do something about it, here and now, without waiting for the slow processes of social evolution. In some cases reform by means of legislation is indeed the only practicable procedure, particularly when a recalcitrant fringe of unsocial competitors has to be whipped into line with the standards which a great majority would be glad to maintain if they could. But to coerce a majority to proceed faster along the path of social progress than they are ready to go, is a

process both difficult and dangerous even though alluring. In such a case, education is more to the point than legislation.

The political type of approach to the problems of today may, of course, succeed in remaking our world, particularly if it be reinforced by plenty of emotion-stirring propaganda. It may even lead to the most effective forms of government that the world has yet seen. These new forms of government are, however, almost certain to be highly centralized, closely integrated forms of government, exerting over industry, and over the lives of citizens generally, the detailed regulation and control which seem to be essential to making any planned economy work. Personally, even if I were sure that the political approach would lead to highly efficient governmental forms and to really well ordered lives, I would rather sacrifice some of this efficiency and orderliness to secure more individual initiative and responsibility, more of a chance for each of us to make his own mistakes and enjoy his own triumphs.

The industrial type of thinking about economic and social problems proceeds in quite a different way. Too often in the past, unfortunately, it has tended to ignore such problems altogether as long as possible, and when at last they loomed up inescapably, to try to fight them instead of to solve them. But the industrial leaders of today are beginning to have an economic and sociological background with which to think through the remoter human implications of the decisions they make and the policies they pursue. They are beginning to work out, step by step, each in his own business unit, some sort of social justice with respect to the conditions and rewards of industrial work and the effect of it on the whole lives of workers. The industrial type of thinking pins its faith to the hope that all these tiny steps forward, scattered all over the country and through many industries, influencing each the other both by the contagion of example, and by the educational process of thoughtful discussion, will integrate into a march of progress that, however halting and irregular it may at times appear to be, will have firm ground under its feet.

The key to the whole economic and social situation, according to this way of thinking, is the breeding of a sufficient supply of industrial administrators who have not only sound business judgment but also enough social understanding and

vision to better adjust the functioning of our present economic and industrial system to the welfare of society at large. Many of us are hoping that such progress will be made rapidly enough to forestall the motivation for, and the possibility of, too much legislative experimentation.

But, you say, where do engineers come into this picture? The answer is that more and more are engineering-trained men finding themselves in positions of executive responsibility in business and industry. There seems to be something about the training and experience of engineers that fits them for such work. Instinctively they deal with facts rather than with traditions and emotional reactions. Their work forces them to see things in the large, to fit details into long range plans, to see visions and dream dreams and then translate them into reality by the careful organization of a multitude of various contributing activities. I believe that engineering-trained men are destined to contribute far more than their proportionate share of the industrial leaders of the next quarter century. If so, they are facing a great opportunity and a great responsibility. If they can learn to think around their jobs as well as thinking their jobs through, if from their natural vantage point as liason officers between capital and labor they can get a comprehensive vision of the aims and aspirations and points of view and prejudices of both groups, if from their familiarity with the flow of materials through a factory or the flow of energy through a power plant they can derive a vivid picture of the flow of goods and of money through the channels of production and consumption, if their experience in handling men on the job can bring to them some understanding of how men want to live, they can, perhaps, contribute more than any other single group to the solution of those fundamental economic and social problems of which we have been speaking. And if by these means they can, even to a small extent, diminish the worries inherent in industrial insecurity, they will have made the greatest contribution of the century to the promotion of the mental health of vast numbers of people.

May I then suggest that he who is profoundly interested in maintaining and improving the health of mankind, and who has enough vision and imagination to sense the long-time

trends of life, would do well to devote a considerable part of his energy, or of his beneficence, to fostering engineering education and research. In particular he should be interested, not only in the technical aspects of the profession, but especially in those branches of it which are concerned with industrial management and with the foundations on which sagacious industrial administration must rest. The results will not be so easy to observe, so directly and immediately obvious, as if he had been instrumental in training a succession of wise physicians or skillful surgeons, or in conquering some obscure disease, but in the long run, he will accomplish much improvement in both the physical and the mental health of his fellow men.